
APPENDIX E

EVALUATION OF HUMAN HEALTH EFFECTS OF OVERLAND TRANSPORTATION

E.1 INTRODUCTION

The overland transportation of any commodity involves a risk to both transportation crew members and members of the public. This risk results directly from transportation-related accidents and indirectly from the increased levels of pollution from vehicle emissions, regardless of the cargo. The transportation of certain materials, such as hazardous or radioactive waste, can pose an additional risk due to the unique nature of the material itself. To permit a complete appraisal of the environmental impacts of the proposed action and alternatives, the human health risks associated with the overland transportation of tritium-producing burnable absorber rods (TPBARs) and associated waste were assessed.

This appendix provides an overview of the approach used to assess the human health risks that may result from overland transportation. The appendix includes discussion of the scope of the assessment, analytical methods used for the risk assessment (i.e., computer models), important assessment assumptions, and determination of potential transportation routes. It also presents the results of the assessment. In addition, to aid in the understanding and interpretation of the results, specific areas of uncertainty are described with an emphasis on how the uncertainties may affect comparisons of the alternatives.

The risk assessment results are presented in this appendix in terms of “per-shipment” risk factors, as well as for the total risks for a given alternative. Per-shipment risk factors provide an estimate of the risk from a single TPBAR or waste shipment. The total risks for a given alternative are found by multiplying the expected number of shipments by the appropriate per-shipment risk factors.

E.2 SCOPE OF ASSESSMENT

The scope of the overland transportation human health risk assessment, including the alternatives and options, transportation activities, potential radiological and nonradiological impacts, and transportation modes considered, is described below. Additional details of the assessment are provided in the remaining sections of the appendix.

Proposed Action and Alternatives

The transportation risk assessment conducted for this environmental impact statement (EIS) estimates the human health risks associated with the transportation of TPBARs and waste for a number of alternatives.

Transportation-Related Activities

The transportation risk assessment is limited to estimating the human health risks incurred during overland transportation for each alternative. The risks to workers or to the public during loading, unloading, and handling prior to or after shipment are not included in the overland transportation assessment, but are addressed in Appendix D of this EIS. Similarly, the transportation risk assessment does not address possible impacts from increased transportation levels on local traffic flow, noise levels, or infrastructure.

Radiological Impacts

For each alternative, radiological risks (i.e., those risks that result from the radioactive nature of the irradiated TPBARs and waste) are assessed for both incident-free (i.e., normal) and accident transportation conditions. The radiological risk associated with incident-free transportation conditions would result from the potential exposure of people to external radiation in the vicinity of a loaded shipment. The radiological risk from transportation accidents would come from the potential release and dispersal of radioactive material into the environment during an accident and the subsequent exposure of people.

All radiological impacts are calculated in terms of committed dose and associated health effects in the exposed populations. The radiation dose calculated is the total effective dose equivalent (see 10 CFR 20), which is the sum of the effective dose equivalent from external radiation exposure and the 50-year committed effective dose equivalent from internal radiation exposure. Radiation doses are presented in units of roentgen equivalent man (rem) for individuals and person-rem for collective populations. The impacts are further expressed as health risks in terms of latent cancer fatalities and cancer incidence in exposed populations using the dose-to-risk conversion factors established by the National Council on Radiation Protection and Measurement (NCRP 1993).

Nonradiological Impacts

In addition to the radiological risks posed by overland transportation activities, vehicle-related risks are also assessed for nonradiological causes (i.e., causes related to the transport vehicles and not the radioactive cargo) for the same transportation routes. The nonradiological transportation risks, which would be incurred for similar shipments of any commodity, are assessed for both incident-free and accident conditions. The nonradiological risks during incident-free transportation conditions would be caused by potential exposure to increased vehicle exhaust emissions. The nonradiological accident risk refers to the potential occurrence of transportation accidents that directly result in fatalities unrelated to the shipment of cargo. State-specific transportation fatality rates are used in the assessment. Nonradiological risks are presented in terms of estimated fatalities.

Transportation Modes

All shipments to the reactors are assumed to take place by truck transportation modes. Additionally, dedicated rail shipments are considered from the commercial light water reactor (CLWR) sites to the U.S. Department of Energy (DOE) Savannah River Site.

Receptors

Transportation-related risks are calculated and presented separately for workers and members of the general public. The workers considered are truck or rail crew members involved in the actual overland transportation. The general public includes all persons who could be exposed to a shipment while it is moving or stopped en route. Potential risks are estimated for the collective populations of exposed people and for the hypothetical maximally exposed individual. For incident-free operation, the maximally exposed individual would be an individual stuck in traffic next to the shipment for 30 minutes. For accident conditions, the maximally exposed individual would be an individual located 33 meters (105 feet) directly downwind from the accident. The collective population risk is a measure of the radiological risk posed to society as a whole by the alternative being considered. As such, the collective population risk is used as the primary means of comparing various alternatives.

E.3 PACKAGING AND REPRESENTATIVE SHIPMENT CONFIGURATIONS

Regulations that govern the transportation of radioactive materials are designed to protect the public from the potential loss or dispersal of radioactive materials, as well as from routine radiation doses during transit. The primary regulatory approach to promote safety is through the specification of standards for the packaging of radioactive materials. Because packaging represents the primary barrier between the radioactive material being transported and radiation exposure to the public and the environment, packaging requirements are an important consideration for transportation risk assessment. Regulatory packaging requirements are discussed briefly below and in Chapter 6. The representative packaging and shipment configurations assumed for this EIS also are described below.

E.3.1 Packaging Overview

Although several Federal and state organizations are involved in the regulation of radioactive waste transportation, primary regulatory responsibility resides with the U.S. Department of Transportation and the U.S. Nuclear Regulatory Commission (NRC). All transportation activities must take place in accordance with the applicable regulations of these agencies as specified in 49 CFR 173 and 10 CFR 71.

Transportation packaging for small quantities of radioactive materials must be designed, constructed, and maintained to contain and shield their contents during normal transport conditions. For large quantities and for more highly radioactive material, such as TPBARs or spent nuclear fuel, they must contain and shield their contents in the event of severe accident conditions. The type of packaging used is determined by the total radioactive hazard presented by the material within the packaging. Four basic types of packaging are used: Excepted, Industrial, Type A, and Type B. Another packaging option, “Strong, Tight,” is still available for some domestic shipments.

Excepted packages are limited to transporting materials with extremely low levels of radioactivity. Industrial packages are used to transport materials that, because of their low concentration of radioactive materials, present a limited hazard to the public and the environment. Type A packages are designed to protect and retain their contents under normal transport conditions and must maintain sufficient shielding to limit radiation exposure to handling personnel. These packages are used to transport radioactive materials with higher concentrations or amounts of radioactivity than Excepted or Industrial packages. Strong, Tight packages are used in the United States for shipment of certain materials with low levels of radioactivity, such as natural uranium and rubble from the decommissioning of nuclear reactors. Type B packages are used to transport material with the highest radioactivity levels and are described in more detail in the following sections.

E.3.2 Regulations Applicable to Type B Casks

Regulations for the transport of radioactive materials in the United States are issued by the U.S. Department of Transportation and are codified in 49 CFR 171–178. The regulation authority for radioactive materials transport is jointly shared by the U.S. Department of Transportation and the NRC. As outlined in a 1979 Memorandum of Understanding with the NRC, the U.S. Department of Transportation specifically regulates the carriers of spent nuclear fuel and the conditions of transport, such as routing, handling and storage, and vehicle and driver requirements. The U.S. Department of Transportation also regulates the labeling, classification, and marking of all spent nuclear fuel packages. The NRC regulates the packaging and transport of spent nuclear fuel for its licensees, which include commercial shippers of spent nuclear fuel. In addition, NRC sets the standards for packages containing fissile materials and spent nuclear fuel.

DOE policy requires compliance with applicable Federal regulations regarding domestic shipments of spent nuclear fuel. Accordingly, DOE has adopted the requirements of 10 CFR 71, “Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions,” and

49 CFR 171–178, “Hazardous Material Regulations.” DOE Headquarters can issue a certificate of compliance for a package to be used only by DOE and its contractors.

E.3.2.1 Cask Design Regulations

Spent nuclear fuel is transported in robust Type B transportation casks that are certified for transporting radioactive materials. Casks designed and certified for spent nuclear fuel transportation within the United States must meet the applicable requirements of the NRC for design, fabrication, operation, and maintenance as contained in 10 CFR 71.

Cask design and fabrication can only be done by approved vendors with established quality assurance programs (10 CFR 71.101). Cask and component suppliers or vendors are required to obtain and maintain documents that prove the materials, processes, tests, instrumentation, measurements, final dimensions, and cask operating characteristics meet the design-basis established in the Safety Analysis Report for Packaging for the cask and that the cask will function as designed.

Regardless of where a transportation cask is designed, fabricated, or certified for use, it must meet certain minimum performance requirements (10 CFR 71.71–71.77). The primary function of a transportation cask is to provide containment and shielding. Casks similar to the designs being considered for TPBARs have been used to transport spent nuclear fuel for many years. Regulations require that casks must be operated, inspected, and maintained to high standards to ensure their ability to contain their contents in the event of a transportation accident (10 CFR 71.87). There are no documented cases of a release of radioactive materials from spent nuclear fuel shipments, even though thousands of shipments have been made by road, rail, and water transport. Further, a number of obsolete casks have been tested under severe accident conditions to demonstrate their adherence to design criteria, without failure. Such tests have demonstrated that transportation casks are fabricated not only to a very high factor of safety; they are even sturdier than required.

Transportation casks are built of heavy, durable structural materials, such as stainless steel. These materials must ensure cask performance under a wide range of temperatures (10 CFR 71.43). In addition to the structural materials, shielding is provided to limit radiation levels at the surface and at prescribed distances from the surface of transportation casks (10 CFR 71.47). Shielding typically consists of dense material, such as lead or depleted uranium. The design for a TPBAR cask is less challenging than the design for a spent nuclear fuel cask because the spent nuclear fuel cask must address additional requirements of criticality control and neutron shielding. Additionally, spent fuel rods are more radioactive, and the effect of the radioactivity is significantly greater for spent fuel rods than tritium rods. The cask cavity can be configured to hold various contents, including irradiated TPBARs or irradiated hardware. The assemblies are supported by internal structures, called baskets, that provide shock and vibration resistance and establish minimum spacing and heat transfer to maintain the temperature of the contents within the limits specified in the Safety Analysis Report for Packaging.

DOE is currently evaluating its approach to procuring transportation packages and/or services. DOE will specify the requirements for packages in great detail. As of publication of this document, it has not been determined whether an existing Type B package will be modified to handle TPBARs or a new package will be designed. The level of safety will be the same in either case. The choice will be based on the ability to economically meet the CLWR program requirements. Typical Type B packages are shown in **Figures E–1** and **E–2**.

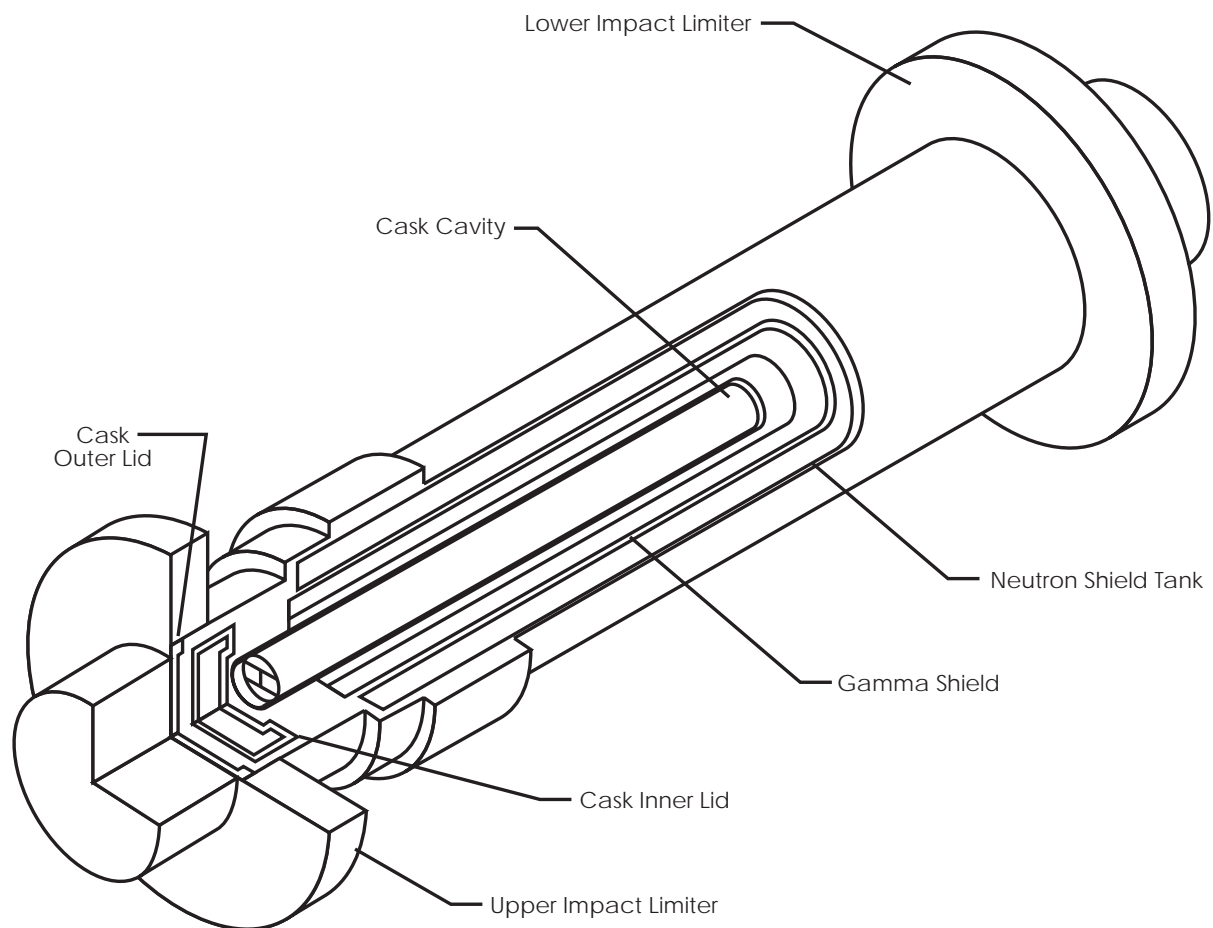


Figure E–1 Typical Type B Legal Weight Track Shipping Cask

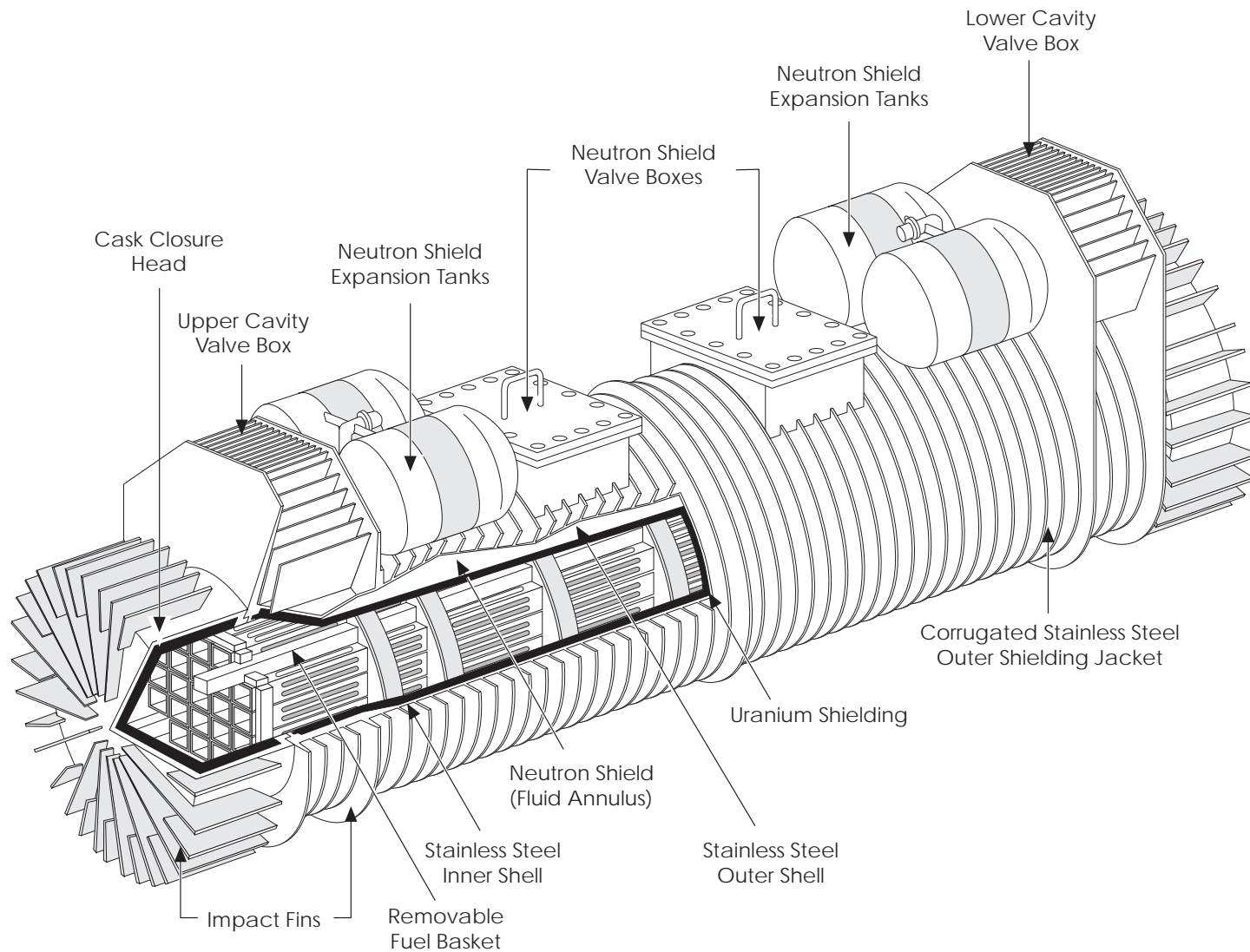


Figure E-2 Typical Type B Rail Shipping Cask

Finally, to limit impact forces and minimize damage to the structural components of a cask in the event of a transportation accident, impact-absorbing structures may be attached to the exterior of the cask. These are usually composed of balsa wood, foam, or aluminum honeycomb designed to readily deform to absorb impact energy. All of these components are designed to work together in order to satisfy the regulatory requirements for a cask to operate under normal conditions of transportation and maintain its integrity in an accident.

E.3.2.2 Design Certification

For certification, transportation casks must be shown by analysis and/or testing to withstand a series of hypothetical accident conditions. These conditions have been internationally accepted as simulating damage to transportation casks that could occur in most reasonably foreseeable accidents. The impact, fire, and water-immersion tests are considered in sequence to determine their cumulative effects on one package. These accident conditions are described in **Figure E–3**. The NRC issues regulations, 10 CFR 71, governing the transportation of radioactive materials. In addition to the tests shown in Figure E–3, the regulations affecting Type B casks require that a transportation cask with activity greater than 10^6 Curies (which is applicable to irradiated TPBARs) be designed and constructed so that its undamaged containment system would withstand an external water pressure of 290 pounds per square inch, or immersion in 200 meters (656 feet) of water, for a period of not less than one hour without collapse, buckling, or allowing water to leak into the cask.

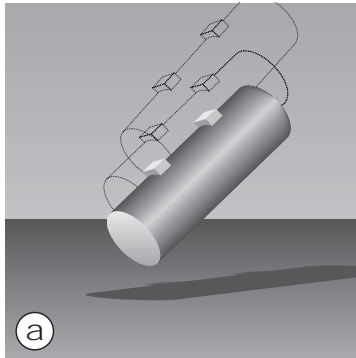
Under the Federal certification program, a Type B packaging design must be supported by a Safety Analysis Report for Packaging, which demonstrates that the design meets Federal packaging standards. The Safety Analysis Report for Packaging must include a description of the proposed packaging in sufficient detail to identify the packaging accurately and provide the basis for evaluating its design. The Safety Analysis Report for Packaging must provide the evaluation of the structural design, materials properties, containment boundary, shielding capabilities, and criticality control, and present the operating procedures, acceptance testing, maintenance program, and the quality assurance program to be used for design and fabrication. Upon completion of a satisfactory review of the Safety Analysis Report for Packaging to verify compliance to the regulations, a Certificate of Compliance is issued.

E.3.2.3 Transportation Regulations

To ensure that the transportation cask is properly prepared for transportation, trained technicians perform numerous inspections and tests (10 CFR 71.87). These tests are designed to ensure that the cask components are properly assembled and meet leak-tightness, thermal, radiation, and contamination limits before shipping radioactive material. The tests and inspections are clearly identified in the Safety Analysis Report for Packaging and/or the Certificate of Compliance for each cask. Casks can be operated only by registered users who conduct operations in accordance with documented and approved quality assurance programs meeting the requirements of the regulatory authorities. Records must be maintained that document proper cask operations in accordance with the quality requirements of 10 CFR 71.91. Reports of defects or accidental mishandling must be submitted to the NRC. DOE will be the Shipper-of-Record for the TPBAR and waste shipments.

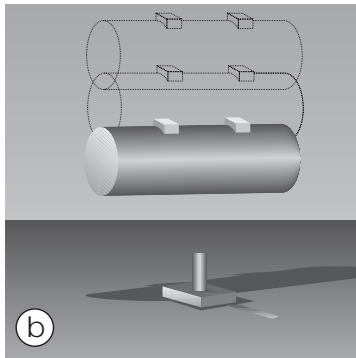
External radiation from a package must be below specified limits that minimize the exposure of handling personnel and the general public. For these types of shipments, the external radiation dose rate during normal transportation conditions must be maintained below the following limits of 49 CFR 173:

- 10 millirem per hour at any point 2 meters (6.6 feet) from the vertical planes projected by the outer lateral surfaces of the transport vehicle (referred to as the regulatory limit throughout this document)



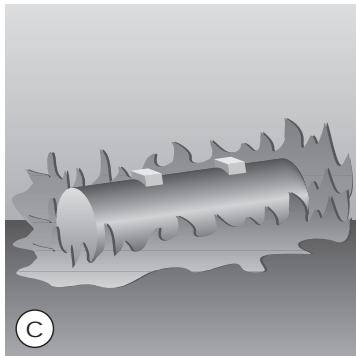
Standards for Type B Casks

For certification by the NRC, a cask must be shown by test or analysis to withstand a series of accident conditions without releasing its contents. These conditions have been internationally accepted as simulating damage to spent fuel casks that could occur in most severe credible accidents. The impact, fire, and water-immersion tests are considered in sequence to determine their cumulative effects on one package. A separate cask is subjected to a deep water-immersion test. The details of the tests are as follows:



Impact

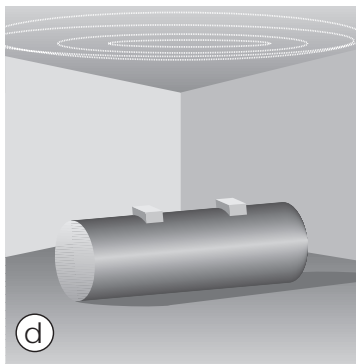
Free Drop (a) – The cask drops 30 feet onto a flat, horizontal, unyielding surface so that it strikes at its weakest point.



Puncture (b) – The cask drops 40 inches onto a 6-inch-diameter steel bar at least 8 inches long; the bar strikes the cask at its most vulnerable spot.

Fire (c)

After the impact tests, the cask is totally engulfed in a 1,475°F thermal environment for 30 minutes.



Water Immersion (d)

The cask is completely submerged under at least 3 feet of water for 8 hours. A separate cask is completely immersed under 50 feet of water for 8 hours.

Figure E-3 Standards for Transportation Casks

- 2 millirem per hour in any normally occupied position in the transport vehicle

Additional restrictions apply to package surface contamination levels, but these restrictions are not important for the transportation radiological risk assessment. For risk assessment purposes, it is important to note that all packaging of a given type is designed to meet the same performance criteria. Therefore, two different Type B designs would be expected to perform similarly during incident-free and accident transportation conditions. The specific containers selected or designed, however, will determine the total number of shipments necessary to transport a given quantity of irradiated TPBARs.

E.3.2.4 Communications

Proper communication assists in ensuring safe preparation and handling of transportation casks. Communication is provided by labels, markings, placarding, shipping papers, or other documents. Labels (49 CFR 172.403) applied to the cask document the contents and the amount of radiation emanating from the cask exterior (transport index). The transport index lists the ionizing radiation level (in millirem per year) at a distance of 1 meter (3.3 feet) from the cask surface.

In addition to the label requirements, markings (49 CFR 173.471) should be placed on the exterior of the cask to show the proper shipping name and the consignor and consignee, in case the cask is separated from its original shipping documents (49 CFR 172.203). Transportation casks are required to be permanently marked with the designation “Type B,” the owner’s (or fabricator’s) name and address, the Certificate of Compliance number, and the gross weight (10 CFR 71.83).

Placards (49 CFR 172.500) are applied to the transport vehicle or freight container holding the transportation cask. The placards indicate the radioactive nature of the contents. Irradiated TPBARs, which constitute a highway route-controlled quantity or “HRCQ,” must be placarded according to 49 CFR 172.507. Placards provide the first responders to a traffic or transportation accident with initial information about the nature of the contents.

Shipping papers for the irradiated TPBARs should contain the notation “HRCQ” and have entries identifying the following: the name of the shipper, emergency response telephone number, description of contents, and the shipper’s certificate, as described in 49 CFR 172, Subpart C.

In addition, drivers of motor vehicles transporting radioactive material must have training in accordance with the requirements of 49 CFR 172.700. The training requirements include familiarization with the regulations, emergency response information, and the communication programs required by the Occupational Safety and Health Administration. Drivers are also required to have training on the procedures necessary for safe operation of the vehicle used to transport the irradiated TPBARs or hardware.

E.3.3 Ground Transportation Route Selection Process

According to DOE guidelines, TPBAR and waste shipments must comply with both NRC and U.S. Department of Transportation regulatory requirements. NRC regulations cover the packaging and transport of irradiated TPBARs and waste, whereas the U.S. Department of Transportation specifically regulates the carriers and the conditions of transport, such as routing, handling and storage, and vehicle and driver requirements. The highway routing of nuclear material is systematically determined according to U.S. Department of Transportation regulations 49 CFR 171–179 and 49 CFR 397 for commercial shipments. Specific routes cannot be identified publicly in advance for DOE’s Transportation Safeguards Division’s shipments because they are classified to protect national security interests.

The U.S. Department of Transportation routing regulations require that shipment of a highway route-controlled quantity of radioactive material be transported over a preferred highway network, including interstate highways, with preference toward interstate system bypasses and beltways around cities and state-designated preferred routes. A state or Tribe may designate a preferred route to replace or supplement the interstate highway system in accordance with U.S. Department of Transportation guidelines (DOT 1992).

Carriers of highway route-controlled quantities are required to use the preferred network unless they are moving from their origin to the nearest interstate highway or from the interstate highway to their destination, are making necessary repair or rest stops, or emergency conditions render the interstate highway unsafe or impassable. The primary criterion for selecting the preferred route for a shipment is travel time. Preferred routing takes into consideration accident rate, transit time population density, activities, time of day, and day of the week.

The HIGHWAY computer code (ORNL 1993a) is used for selecting highway routes in the United States. The HIGHWAY database is a computerized road atlas that currently describes about 386,400 kilometers (240,000 miles) of roads. The Interstate System and all U.S. (U.S.-designated) highways are completely described in the database. In addition, most of the principal state highways and many local and community roads are also identified. The code is updated periodically to reflect current road conditions and has been benchmarked against reported mileages and observations of commercial truck firms. Features in the HIGHWAY code allow the user to select routes that conform to U.S. Department of Transportation regulations. Additionally, the HIGHWAY code contains data on the population densities along the routes. The distances and populations from the HIGHWAY code are part of the information used for the transportation impact analysis in this EIS.

The INTERLINE (ORNL 1993b) computer program, designed to simulate routing of the U.S. rail system, is used for selecting railway routes for the purpose of analysis. The INTERLINE database consists of 94 separate subnetworks and represents various competing rail companies in the United States. The database used by INTERLINE was originally based on Federal Railroad Administration data and reflected the U.S. railroad system in 1974. The database has since been expanded and modified over the past two decades. The code is updated periodically to reflect current track conditions and has been benchmarked against reported mileages and observations of commercial rail firms. The INTERLINE model uses a shortest-route algorithm that finds the minimum impedance path within an individual subnetwork. A separate routine is used to find paths along the subnetworks. The routes selected for this study used the standard assumptions in the INTERLINE model that simulate the selection process that railroads use to direct shipments.

E.4 METHODS FOR CALCULATING TRANSPORTATION RISKS

The overland transportation risk assessment method is summarized in **Figure E-4**. After the EIS alternatives were identified and the goals of the shipping campaign were understood, data was collected on material characteristics and accident parameters. Accident parameters were largely based on the DOE-funded study of transportation accidents (ANL 1994).

Representative routes that may be used for the shipment of TPBARs and waste were selected for risk assessment purposes using the HIGHWAY code. They do not necessarily represent the actual routes that would be used to transport nuclear materials. Specific routes cannot be identified in advance because the routes cannot be finalized until they have been reviewed and approved by the NRC. The selection of the actual route would be responsive to environmental and other conditions that would be in effect or could be predicted at the time of shipment. Such conditions could include adverse weather conditions, road conditions, bridge closures, and local traffic problems. For security reasons, details about a route would not be publicized before the shipment.

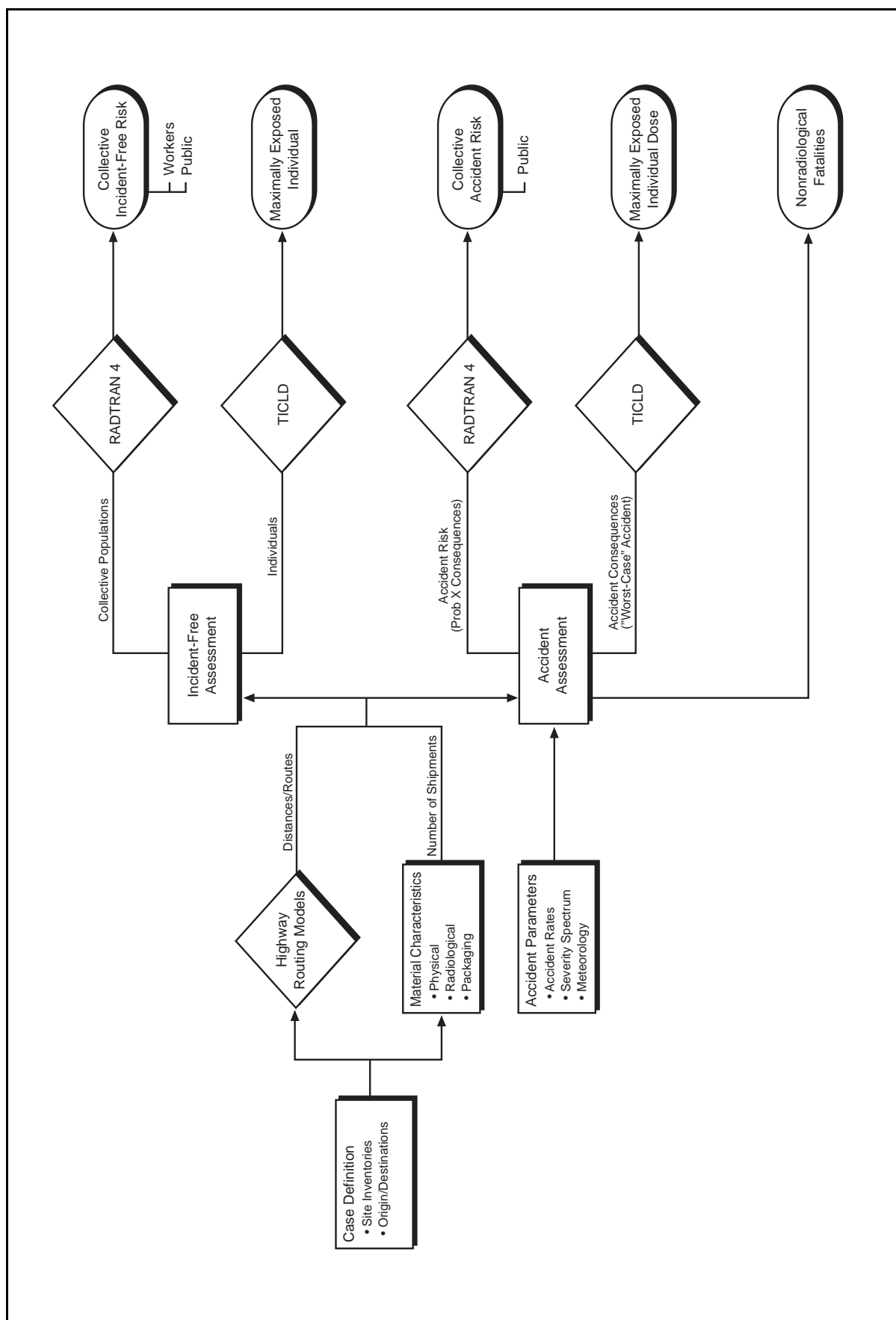


Figure E-4 Overland Transportation Risk Assessment

The first analytic step in the ground transportation analysis was to determine the incident-free and accident risk factors on a per-shipment basis. Risk factors, as with any risk estimate, are the product of the probability of exposure and the magnitude of the exposure. Accident risk factors were calculated for radiological and nonradiological traffic accidents. The probabilities, which are much lower than one, and the magnitudes of exposure were multiplied, yielding very low risk numbers. Incident-free risk factors were calculated for crew and public exposure to radiation emanating from the shipping container (cask) and public exposure to the chemical toxicity of the transportation vehicle exhaust. The probability of incident-free exposure is unity (one).

For each alternative, risks were assessed for both incident-free transportation and accident conditions. For the incident-free assessment, risks are calculated for both collective populations of potentially exposed individuals and for maximally exposed individuals. The accident assessment consists of two components: (1) a probabilistic accident risk assessment that considers the probabilities and consequences of a range of possible transportation accident environments, including low-probability accidents that have high consequences and high-probability accidents that have low consequences, and (2) an accident consequence assessment that considers only the consequences of the most severe postulated transportation accidents.

The RADTRAN 4 computer code (SNL 1993b) is used for incident-free and accident risk assessments to estimate the impacts on populations. RADTRAN 4 was developed by Sandia National Laboratories to calculate population risks associated with the transportation of radioactive materials by a variety of modes, including truck, rail, air, ship, and barge. The Transportation Incident Center Line Dose (TICLD) code, run in conjunction with RADTRAN 4, was used to calculate the doses to the maximally exposed individuals.

The RADTRAN 4 population risk calculations take into account both the consequences and probabilities of potential exposure events. The RADTRAN 4 and TICLD codes consequence analyses include the cloud shine, ground shine, inhalation, and resuspension exposures. The collective population risk is a measure of the total radiological risk posed to society as a whole by the alternative being considered. As such, the collective population risk is used as the primary means of comparing the various alternatives.

E.5 ALTERNATIVES, PARAMETERS, AND ASSUMPTIONS

E.5.1 Description of Alternatives

Four transportation segments were evaluated in this EIS: (1) shipment of fabricated TPBARs to assembly facilities, (2) shipment of TPBAR assemblies to each of the CLWRs, (3) shipment of irradiated TPBARs to the Savannah River Site, and (4) shipment of irradiated hardware to a waste disposal site.

Transportation segment 1 involves shipment of nonhazardous, nonradioactive TPBAR material in secure commercial containers from TPBAR fabricators to fuel assembly facilities. Candidate sites for fabrication of the TPBARs include Wilmington, North Carolina (General Electric); Hematite, Missouri (Asea Brown-Boveri/Combustion Engineering); and Columbia, South Carolina (Westinghouse Electric Corporation).

Transportation segment 2 involves shipment of nonhazardous, nonradioactive TPBAR material in secure commercial containers, along with new (fresh, unirradiated) reactor fuel. The impacts of shipping fresh reactor fuel are outside the scope of this EIS and are covered in NUREG-0170 (NRC 1977). Candidate sites for assembly of the TPBARs include Richland, Washington (Siemens Power Corporation); Lynchburg, Virginia (Framatome-Cogema Fuels or BWX Technologies, Inc.); Hematite, Missouri (Asea Brown-Boveri/Combustion Engineering); and Columbia, South Carolina (Westinghouse Electric Corporation). The transportation impacts of all possible combinations of these facilities have been evaluated. The choice of facilities will be made by DOE using normal commercial practices.

Transportation segment 3 involves shipment of irradiated TPBARs from the CLWRs to the Tritium Extraction Facility at the Savannah River Site. The metallic components of the TPBARs will have been activated by the reactor flux, and they will contain the radioactive tritium. Therefore, these TPBARs will be shipped in a Type B cask. This EIS has evaluated the shipment of TPBARs by three distinct methods. First, truck-sized casks, which hold a single consolidated assembly, could be transported using legal-weight trucks (one cask per truck) on public roads. Second, two truck-sized casks could be shipped by dedicated train on rail lines. Third, rail-sized casks, which hold between 2 and 24 consolidated TPBAR containers, could be shipped by dedicated train on rail lines. For the purpose of conservative analysis, this EIS assumes that only two consolidated containers will be loaded in a rail-size cask. This assumption is conservative because putting more than two consolidated assemblies into a cask would decrease the number of shipments, which decreases the incident-free and traffic accident risks. These risks are dominant contributors of the transportation risk.

The transportation analysis looked at likely implementation approaches for each of the three reactor options. The approaches quantitatively addressed minimum production at a single unit (1,000 TPBARs per 18-month fuel cycle) and maximum production at a single unit (3,400 TPBARs per 18-month fuel cycle).

Transportation segment 4 involves shipment of irradiated hardware from the CLWRs to either the Savannah River Site or the Barnwell disposal facility in South Carolina for disposal as low-level radioactive waste. Irradiated hardware includes base plates and thimble plugs removed from the TPBARs at the CLWR site.

E.5.2 Representative Routes

Representative overland truck routes were selected for the shipments to the CLWRs, the Savannah River Site, and the Barnwell waste disposal facility. The routes were selected consistent with current routing practices and all applicable routing regulations and guidelines (DOT 1992). However, the routes were determined for risk assessment purposes. They do not necessarily represent the actual routes that would be used to transport TPBARs and waste in the future. Specific routes cannot be identified in advance. The representative truck routes are shown in **Figure E-5**. Rail routes, determined by commercial as well as safety considerations, are not shown on Figure E-5 for brevity.

Route characteristics that are important to the radiological risk assessment include the total shipment distance and the population distribution along the route. The specific route selected determines both the total potentially exposed population and the expected frequency of transportation-related accidents. Route characteristics are summarized in **Table E-1**. The population densities along each route are derived from 1990 U.S. Bureau of Census data. Rural, suburban, and urban areas are characterized according to the following breakdown: rural population densities range from 0 to 54 persons per square kilometer (0 to 139 person per square mile); the suburban range is from 55 to 1,284 persons per square kilometer (140 to 3,326 persons per square mile); and the urban range includes all population densities greater than 1,284 persons per square kilometer (3,326 persons per square mile). The exposed population includes all persons living within 800 meters (0.5 mile) of each side of the road. The exposed population, for the purpose of route characterization and incident-free dose calculation, includes all persons living within 800 meters (0.5 mile) of each side of the road.

The preferred route for truck shipments entering the Savannah River Site is to enter the site from Jackson, South Carolina, on Route 125 at barricade 7; take Road 3 over to Road 5; go south on Road 5 until reaching Road 6; go east on Road 6 until reaching F Road; go north on F Road until reaching E Road; go north on E Road until reaching Road 4; go north on Road 4 into the H-area; and then approach the Tritium Extraction Facility via the local H-area roads. DOE has identified two alternate routes (WSRC 1996):

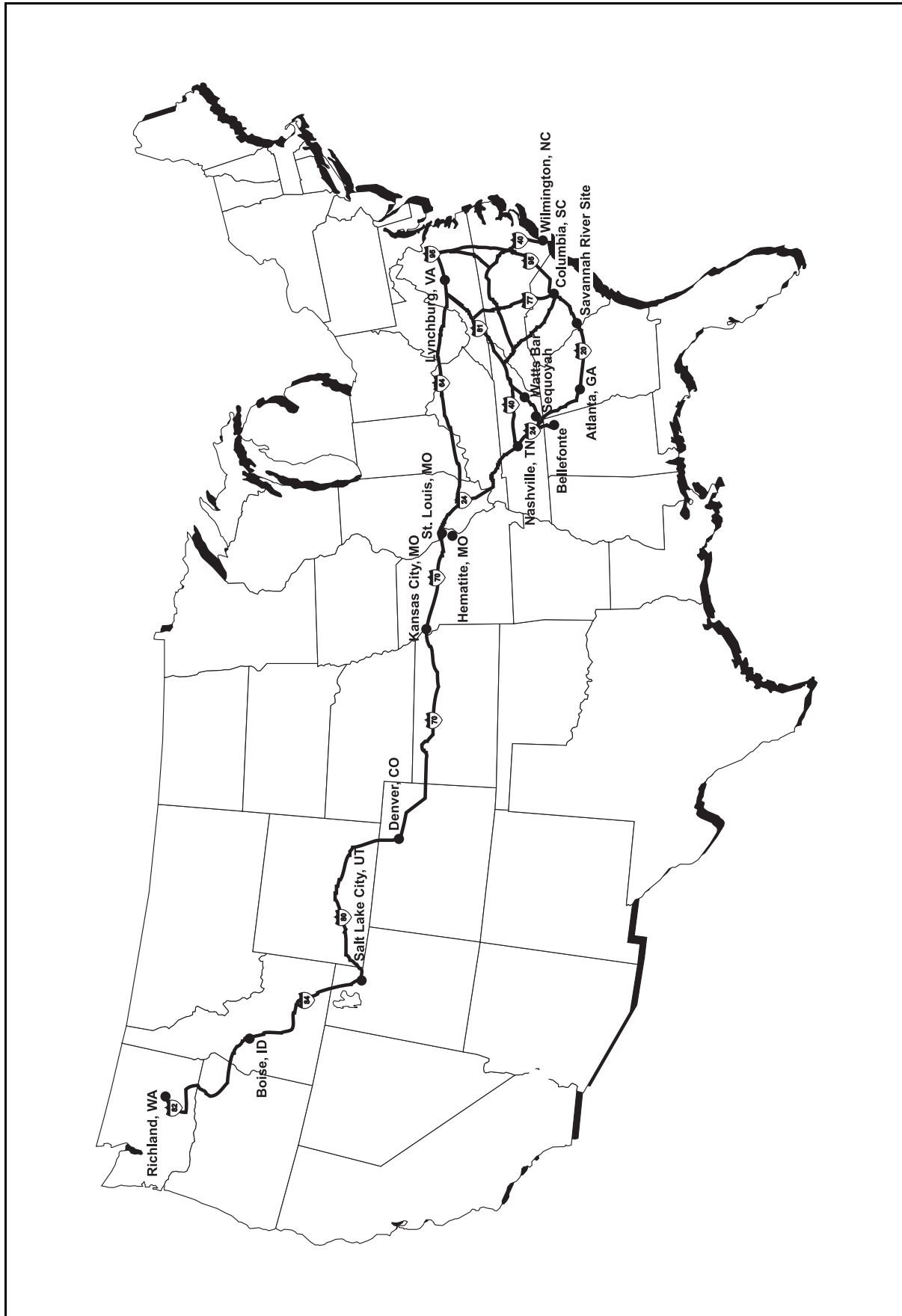


Figure E-5 Representative Overland Truck Routes

Table E-1 Potential Shipping Routes Evaluated for the CLWR EIS

From	To	Distance (kilometers)	Percentages in Zones			Population Density in Zone (persons per square kilometer)			Number of Affected Persons
			Rural	Suburban	Urban	Rural	Suburban	Urban	
Truck Routes									
Watts Bar Nuclear Plant	Savannah River Site	574.5	61.7	34.9	3.4	18.1	349.7	2,195.3	191,000
Sequoyah Nuclear Plant	Savannah River Site	498.9	55.0	40.6	4.4	16.8	373.0	2,157.4	204,000
Bellefonte Nuclear Plant	Savannah River Site	560.0	61.7	34.5	3.8	16.7	358.4	2,158.0	193,000
Wilmington, NC	Columbia, SC	513.4	72.3	27.2	0.4	19.9	229.3	1,764.7	69,000
Wilmington, NC	Hematite, MO	1,673.7	70.8	28.3	0.8	14.1	294.9	2,229.9	298,000
Wilmington, NC	Lynchburg, VA	577.7	83.0	16.1	0.7	14.4	188.7	2,276.9	54,000
Wilmington, NC	Richland, WA	4,787.7	82.7	16.1	1.2	7.4	329.5	2,169.9	653,000
Columbia, SC	Lynchburg, VA	595.4	70.0	28.7	1.3	16.9	296.5	2,037.7	118,000
Columbia, SC	Richland, WA	4,451.3	85.7	13.1	1.2	6.7	336.5	2,146.8	538,000
Hematite, MO	Columbia, SC	1,337.3	77.8	21.3	0.9	12.7	286.4	2,134.2	193,000
Hematite, MO	Watts Bar Nuclear Plant	917.3	83.0	16.2	0.8	12.2	253.1	2,321.9	102,000
Lynchburg, VA	Watts Bar Nuclear Plant	614.8	69.6	29.6	0.8	18.7	276.3	2,028.9	109,000
Columbia, SC	Watts Bar Nuclear Plant	552.0	70.0	29.1	0.9	14.2	297.0	1,856.0	100,000
Richland, WA	Watts Bar Nuclear Plant	4,031.3	87.7	11.0	1.2	6.2	340.7	2,174.7	445,000
Hematite, MO	Sequoyah Nuclear Plant	836.8	79.2	19.9	1.0	13.0	280.2	2,297.9	119,000
Lynchburg, VA	Sequoyah Nuclear Plant	729.0	64.7	34.2	1.1	19.3	302.4	1,967.3	160,000
Columbia, SC	Sequoyah Nuclear Plant	597.1	57.1	39.5	3.4	16.0	348.2	2,110.6	209,000
Richland, WA	Sequoyah Nuclear Plant	3,950.8	87.0	11.7	1.3	6.2	347.2	2,173.3	469,000
Hematite, MO	Bellefonte Nuclear Plant	811.1	82.0	17.1	0.9	13.0	266.4	2,313.2	100,000
Lynchburg, VA	Bellefonte Nuclear Plant	790.2	68.8	30.3	0.9	18.9	287.8	1,950.5	149,000
Columbia, SC	Bellefonte Nuclear Plant	658.2	62.6	34.4	3.0	16.0	334.7	2,109.6	198,000
Richland, WA	Bellefonte Nuclear Plant	3,925.1	87.6	11.1	1.3	6.2	347.0	2,173.8	453,000
Watts Bar Nuclear Plant	Barnwell, SC	632.5	62.9	34.3	2.8	16.5	342.3	2,145.2	190,000
Sequoyah Nuclear Plan	Barnwell, SC	556.8	57.0	39.3	3.7	14.9	364.0	2,110.7	205,000
Bellefonte Nuclear Plant	Barnwell, SC	618.0	62.9	33.9	3.2	15.2	350.1	2,109.8	194,000

From	To	Distance (kilometers)	Percentages in Zones			Population Density in Zone (persons per square kilometer)			Number of Affected Persons
			Rural	Suburban	Urban	Rural	Suburban	Urban	
Rail Routes									
Watts Bar Nuclear Plant	Savannah River Site	668.2	62.4	36.2	1.3	14.1	269.0	2,091.1	143,000
Sequoyah Nuclear Plant	Savannah River Site	611.9	60.5	38.0	1.4	14.3	271.4	2,091.1	138,000
Bellefonte Nuclear Plant	Savannah River Site	675.9	63.3	35.4	1.2	14.0	268.8	2,091.1	140,000

- Assuming that the newly completed bridge modification on Road F is adequate to handle trucks, enter the site from Jackson, South Carolina, on Route 125 at barricade 7. Take Road 3 over to Road 5. Go northeast on Road 5 until reaching C Road. Go north on C Road until reaching Road 4. Go northeast on Road 4 into the H-area, and approach the Tritium Extraction Facility via the local H-area roads.
- Assuming that the newly completed bridge on Road F is adequate to handle trucks, enter the site from the North on Route 19 through barricade 2. Take road 2 to F Road. Go south on F Road until reaching Road 4. Go southeast on Road 4 into the H-area, and approach the Tritium Extraction Facility via the local H-area roads.

The differences in the risk of the three possible routes were evaluated to be much less than the significant figures shown on the risk estimates. Final determination of route details is an operational decision to be made at the time of shipment.

If rail transportation is the chosen mode, the preferred rail system is to use existing Savannah River Site rails and railspurs. The Savannah River Site would use an existing 300-ton Manitowoc portable crane at the end of the rail spur to transfer the casks from the rail car to trucks. The trucks would travel the quarter mile to the Tritium Extraction Facility. A railspur terminal support facility may be required to support this crane. Construction impact estimates (if construction is required) are not available at this time (WSRC 1996).

The Bellefonte, Watts Bar, and Sequoyah Nuclear Plants currently have cranes that could handle 125-ton casks, although Sequoyah is currently downgraded to 80 tons and load testing would be required to restore the rating to the design capacity of 125 tons. Large cask handling has not been addressed in detail at any of the sites, so regulatory, structural, and spacial issues must be evaluated before rail transportation could be implemented.

E.5.3 Material Inventory

The amount of hazardous material in a package is called the inventory. It refers to the material available for release in an accident scenario. Inventory estimates for the materials shipped are given below.

Low-Level Radioactive Waste

DOE assumes 24 TPBARs per production assembly. Irradiation of 3,400 TPBARs per 18-month fuel cycle would generate 141 hold-down assemblies (see Appendix A, **Figure A-12**). These hold-down assemblies would be discarded as low-level radioactive waste. The low-level radioactive waste volume is estimated to be about 0.43 cubic meters (15 cubic feet) per year (WEC 1998).

Use of a “generic legal weight truck waste cask” with a usable cavity measuring 18 inches in diameter by 144 inches long would result in about two shipments per year. However, achieving perfect packing efficiency of these wastes is not realistic, and this estimate must be expanded. DOE estimates that the annual waste shipments will be a minimum of two and a maximum of eight.

Pacific Northwest National Laboratory provided source terms for 16 thimble plugs, which are equal to about 1,500 grams of irradiated hardware (PNNL 1998). Using the above information, which was chosen to conservatively estimate the amount of irradiated hardware, each shipment will carry about 56 kilograms of irradiated hardware. The thimble plugs are more highly irradiated than other hardware, so use of the data from thimble plugs is conservative. **Table E–2** lists the derived source term used for the purpose of analyzing low-level radioactive waste transportation risks. Further analysis, using final design information and actual irradiation schedules, will be used to verify that the concentration of radionuclides does not exceed the Class C limits of 10 CFR 61. The regulatory limit dose rates were assumed for low-level radioactive waste shipments.

TPBARs

Pacific Northwest National Laboratory determined the radionuclide inventory and decay heat for the Lead Test Assembly TPBARs at reactor discharge and for decay times ranging from 7 days to 10 years following reactor discharge (PNNL 1998). Table E–2 shows the TPBAR radionuclide inventory, with a decay time of 30 days used for the analysis. The inventory includes tritium and other irradiated components associated with the cladding, liner, getter, and other structures within a TPBAR. The latter is collectively called nontarget-bearing components.

Crud

The crud inventory assumed to be available for release from TPBARs is shown in Table E–2 with a 30-day decay time following reactor discharge in units of Curies/TPBAR. The crud inventory has been very conservatively bounded using worst-case measurements of crud from pressurized water reactor spent nuclear fuel (SNL 1991a).

Table E–2 Irradiated Hardware and TPBAR Inventory

<i>Nuclide</i>	<i>Low-Level Radioactive Waste (Curies per shipment)</i>	<i>TPBAR (Curies per TPBAR)</i>	<i>TPBAR Crud (Curies per TPBAR)</i>
Tritium		9,600 ^a	
Carbon-14	0.0000042	0.0095	NA
Chromium-51	30,000	300	0.21
Manganese-54	2,700	23	0.4
Iron-55	14,000	120	NA
Iron-59	890	7.5	0.21
Cobalt-58	3,400	66	1.2
Cobalt-60	3,500	33	0.15
Zinc-65	0.000038	0.0015	NA
Zirconium-89	0.000029	0.0000022	NA
Zirconium-95	0.04	31	0.029
Niobium-95	8.1	.39	NA
Molybdenum-99	2.6	0.19	NA
Ruthenium-103	0.014	0.0010	NA

^a For a failed TPBAR, a value of 1.15×10^4 Curies of tritium (1.2 grams of tritium) per TPBAR is used for analytic consistency. NA = Not available

E.5.4 External Dose Rates

Cask design for irradiated TPBARs and cask selection for low-level radioactive waste are not complete. However, even though the hardware is highly irradiated, the container external dose rate is not as high as the regulatory limits. For the purposes of analysis, it is conservative to assume that TPBAR and low-level radioactive waste container external dose rates are equal to regulatory limits.

E.5.5 Health Risk Conversion Factors

The health risk conversion factors used to estimate expected cancer fatalities were: 0.0005 and 0.0004 fatal cancer cases per person-rem for members of the public and workers, respectively (NCRP 1993).

E.5.6 Accident Involvement Rates

For the calculation of accident risks, vehicle accident and fatality rates are taken from data provided in other reports (ANL 1994). Accident rates are generically defined as the number of accident involvements (or fatalities) in a given year per unit of travel in that same year. Therefore, the rate is a fractional value, with accident-involvement count as the numerator of the fraction and vehicular activity (total travel distance in truck-kilometers or railcar-kilometers) as its denominator. Accident rates are generally determined for a multi-year period. For assessment purposes, the total number of expected accidents or fatalities is calculated by multiplying the total shipment distance for a specific case by the appropriate accident or fatality rate.

For truck transportation, the rates presented are specifically for heavy combination trucks involved in interstate commerce (ANL 1994). Heavy combination trucks are rigs composed of a separable tractor unit containing the engine and one to three freight trailers connected to each other. Heavy combination trucks are typically used for radioactive waste shipments. The truck accident rates are computed for each state based on statistics compiled by the U.S. Department of Transportation Office of Motor Carriers from 1986 to 1988. Saricks and Kvitek present accident involvement and fatality counts; estimated kilometers of travel by state; and the corresponding average accident involvement, fatality, and injury rates for the three years investigated. A fatality caused by an accident is the death of a member of the public who is killed instantly or dies within 30 days due to the injuries sustained in the accident.

Rail accident rates are computed and presented similarly to truck accident rates (ANL 1994). The state-specific rail accident involvement and fatality rates are based on statistics compiled by the Federal Railroad Administration from 1985 to 1988. Rail accident rates include both main line accidents and those occurring in railyards. It is important to note that the accident rates used in this assessment were computed using the universe of all interstate heavy combination truck shipments, independent of shipment cargo. The cited report points out that shippers and carriers of radioactive material generally have a higher than average awareness of transport risk and prepare cargoes and drivers for such shipments accordingly (ANL 1994). This preparation should have a twofold effect of reducing component/equipment failure and mitigating the human error contribution to accidents. These effects were not given credit in the accident assessment.

E.5.7 Container Accident Response Characteristics and Release Fractions

E.5.7.1 Development of Conditional Probabilities

The Modal Study was the result of an initiative taken by the NRC (NRC 1987) to refine more precisely the analysis presented in NUREG-0170 (NRC 1977) for spent nuclear fuel shipping casks. Whereas the NUREG-0170 analysis was primarily performed using best engineering judgments and presumptions concerning cask response, the Modal Study relies on sophisticated structural and thermal engineering analysis

and a probabilistic assessment of the conditions that could be experienced in severe transportation accidents. The Modal Study results are based on representative spent nuclear fuel casks that were assumed to have been designed, manufactured, operated, and maintained in accordance with national codes and standards. Design parameters of the representative casks were chosen to meet the minimum test criteria specified in 10 CFR 71. The study is believed to provide realistic, yet conservative, results for radiological releases under transport accident conditions.

In the Modal Study, potential accident damage to a cask is categorized according to the magnitude of the mechanical forces (impact) and thermal forces (fire) to which a cask may be subjected during an accident. Because all accidents can be described in these terms, severity is independent of the specific accident sequence. In other words, any sequence of events that results in an accident in which a cask is subjected to forces within a certain range of values is assigned to the accident severity region associated with that range. The accident severity scheme is designed to take into account all potential foreseeable transportation accidents, including accidents with low probability but high consequences and those with high probability but low consequences.

Each severity region actually represents a set of accidents defined by a combination of mechanical and thermal forces. A conditional probability of occurrence—that is, the probability that if an accident occurs, it is of a particular severity—is assigned to each region. The Modal Study conditional probability matrices for truck and train accidents (see **Figures E-6** and **E-7**) each contain 20 accident regions. In the Modal Study, these regions are collapsed to form six severity categories, where a severity category represents a set of accidents defined by a combination of mechanical and thermal forces that are expected to produce accident source terms that have similar magnitudes. The fraction of all accidents that fall into each severity category is developed by summing the values for the fractions of all accidents presented in the Modal Study for the set of regions combined to form one severity category. Figure E-6 indicates the regions that were combined to generate each of the six accident categories specified in DOE/EIS-0203-F (DOE 1995) and DOE/EA-1210 (DOE 1997). The y-axis breakpoints on the accident matrix ($S_1 = 0.2$ percent, $S_2 = 2$ percent, $S_3 = 30$ percent) specify the maximum strain in percent on the inner shell of the Type B truck cask. The x-axis breakpoints ($T_1 = 260^\circ\text{C}$, $T_2 = 316^\circ\text{C}$, $T_3 = 343^\circ\text{C}$, $T_4 = 565^\circ\text{C}$) specify the lead mid-wall temperature. Thus, each of the 20 regions in the matrix specifies both an impact load and a thermal load. Figure E-7 presents the Modal Study matrix for rail accidents and gives the conditional probability for each of the 20 accident regions. The y-axis and x-axis breakpoints are the same as those developed for the Modal Study truck accident matrix. The regions have not been grouped into categories for TPBAR performance in train accidents, so none are presented.

Accidents in Region (1,1) are the least severe but most frequent, whereas accidents in Region (4,5) are very severe but very infrequent. To determine the expected frequency of an accident of a given severity, the conditional probability in the category is multiplied by the baseline accident rate. The entire spectrum of accident severities is considered in the accident risk assessment.

As discussed above, the accident consequence assessment only considers the potential impacts from the most severe transportation accidents. In terms of risk, the severity of an accident must be viewed in terms of potential radiological consequences, which are directly proportional to the fraction of the radioactive material within a cask that is released to the environment during the accident. Although regions span the entire range of mechanical and thermal accident loads, they are grouped into accident categories that can be characterized by a single set of release fractions and are, therefore, considered together in the accident consequence assessment. The accident category severity fraction is the sum of all conditional probabilities in that accident category.

To use the conditional probabilities developed in the Modal Study for Rail Casks Transported by Rail for the case of truck casks transported by rail, a comparison of the effect of rail accidents on truck casks was made. The response of truck and rail casks to rail accident impacts is essentially identical; therefore, no adjustment was required. However, these casks would respond differently to a rail accident involving fire. For the same

design-basis fire environment, the truck cask will reach a given temperature in a shorter duration than the rail cask. The Modal Study provides graphs that relate the fire duration with lead mid-wall temperature for both truck and rail casks. Using the graph for rail casks, the durations of engulfing fires required to reach each of the x-axis breakpoints were determined. From these durations, the graph for truck casks was used to develop new x-axis breakpoints. An exponential function was fitted to the resulting cumulative probability versus mid-wall temperature data, and it was then applied to determine the cumulative probability for the original Modal Study x-axis breakpoints. The resulting conditional probabilities for truck casks transported by rail are given in **Figure E-8**.

Strain	R(4,1) 1.532E-7	R(4,2) 3.926E-14	R(4,3) 1.495E-14	R(4,4) 7.681E-16	R(4,5) <1.0E-16 Category 6
S ₃					
30%	R(3,1) 1.7984E-3	R(3,2) 1.574E-7 Category 5	R(3,3) 2.034E-7	R(3,4) 1.076E-7	R(3,5) 4.873E-8
S ₂					
2%	R(2,1) 3.8192E-3	R(2,2) 2.330E-7 Category 3	R(2,3) 3.008E-7	R(2,4) 1.592E-7 Category 4	R(2,5) 7.201E-8
S ₁					
0.2%	R(1,1) 0.99431 Category 1	R(1,2) 1.687E-5 Category 2	R(1,3) 2.362E-5	R(1,4) 1.525E-5	R(1,5) 9.570E-6
	T ₁ 260°C	T ₂ 316°C	T ₃ 343°C	T ₄ 565°C	
	Temperature				

1.532E-7 = 1.532 x 10⁻⁷

Figure E-6 Conditional Probability Matrix for Modal Study Truck Cask

Strain	R(4,1) 1.786E-9	R(4,2) 3.290E-13	R(4,3) 2.137E-13	R(4,4) 1.644E-13	R(4,5) 3.459E-14
S ₃					
30%	R(3,1) 5.545E-4	R(3,2) 1.021E-7	R(3,3) 6.634E-8	R(3,4) 5.162E-8	R(3,5) 5.296E-8
S ₂					
2%	R(2,1) 2.7204E-3	R(2,2) 5.011E-7	R(2,3) 3.255E-7	R(2,4) 2.531E-7	R(2,5) 1.075E-8
S ₁					
0.2%	R(1,1) 0.993962	R(1,2) 1.2275E-3	R(1,3) 7.9511E-4	R(1,4) 6.140E-4	R(1,5) 1.249E-4
	T ₁ 260°C	T ₂ 316°C	T ₃ 343°C	T ₄ 565°C	
	Temperature				

1.786E-9 = 1.786 x 10⁻⁹

Figure E-7 Conditional Probability Matrix for Modal Study Rail Cask

Strain	R(4,1) 1.786E-7	R(4,2) 1.659E-13	R(4,3) 2.777E-13	R(4,4) 2.091E-13	R(4,5) 1.361E-13
S ₃ 30%	R(3,1) 5.544E-4	R(3,2) 5.148E-8	R(3,3) 8.621E-8	R(3,4) 6.565E-8	R(3,5) 2.084E-7
S ₂ 2%	R(2,1) 2.7204E-3	R(2,2) 2.523E-7	R(2,3) 4.230E-7	R(2,4) 3.219E-7	R(2,5) 4.230E-8
S ₁ 0.2%	R(1,1) 0.99380	R(1,2) 6.190E-4	R(1,3) 1.033E-3	R(1,4) 7.808E-4	R(1,5) 4.914E-4
	T ₁ 260°C	T ₂ 316°C	T ₃ 343°C	T ₄ 565°C	
	Temperature				
	1.786E-7 = 1.786 x 10 ⁻⁷				

Figure E–8 Conditional Probability Matrix for Truck Cask Transported by Rail

E.5.7.2 Transportation Risk Analyses Assumptions

E.5.7.2.1 Cask Response to Impact and Thermal Loads

This section provides separate analyses for casks with elastomeric seals and metallic seals, since they perform differently in accidents. In general, elastomeric seals will perform better (i.e., fail at a higher strain) than metallic seals in accidents involving impacts without fires. Metallic seals will perform better (i.e., fail at a higher temperature) than elastomeric seals in accidents involving fires.

The regulatory design-basis accident defined by 10 CFR 71 and 49 CFR 173 is encompassed within a region bounded by a maximum impact load of S₁ (0.2 percent maximum strain on the inner shell) and a maximum thermal load of T₁ (260°C [500°F] lead shield mid-wall temperature).

The cask containment boundary for a truck or rail cask using elastomeric seals was assumed not to fail for impact loads less than S₂ (2 percent strain) and temperatures less than T₁. Radioactive material packages are designed to a very rigorous set of standards. This design philosophy results in a large margin of safety against accidents more severe than the design-basis accident. For the EIS analyses, the conditional probabilities were taken directly from the Modal Study, and those conditional probabilities were based on the response of the representative truck and rail casks described in the Modal Study. These generic casks were chosen such that the regulatory design-basis accident would result in a 0.2 percent strain in the inner shell of the cask. Recent tests and analyses performed at Sandia National Laboratory using packages with elastomeric seals have shown that this level of strain is reasonable for the design-basis accident and that the cask containment boundary does not fail for accidents resulting in inner shell strains of up to 20 percent (Ammerman 1995). Based on these results, the EIS transportation risk analyses assumed that the cask containment boundary will not fail for packages using elastomeric seals for inner shell strains less than S₂.

Packages using metallic seals cannot tolerate the slight amounts of closure movements that may occur during extra-regulatory impacts. Therefore, the EIS analyses assume that any impact load above S_1 for a cask using metallic seals results in failure of the cask containment boundary. The probability of failure of the cask containment boundary as a result of failure of the metallic seal below T_4 (565°C) is similar to the negligible probability of seal failure for normal operating conditions. The American Society for Testing and Materials Type 304 stainless steel structural materials and metallic seal materials typically used in radioactive material packages are also used in high-temperature industrial applications. To avoid creep, the American Society of Mechanical Engineers Code, Section III, rates the American Society for Testing and Materials Type 304 material commonly used for radioactive material packages at 122 mega-Pascal (17.7 thousand pounds per square inch) for a 10-hour exposure to temperatures of 565°C. With only internal pressure as a source of primary stresses and secondary thermal stresses, stress levels in the seal area are anticipated to be well below this material rating. However, bolt materials for package closures must be carefully selected. The American Society of Mechanical Engineers Codes, Sections VIII and III, rate common high-strength carbon steel bolt materials only to temperatures near 370°C for most applications. Inconel bolts, however, are rated to temperatures as high as 620°C, and these analyses have assumed that high-temperature bolts will be utilized (SNL 1999).

E.5.7.2.2 TPBARs Response to Impact and Thermal Loads

The EIS transportation risk analyses assumed a TPBAR failure rate, consistent with the assumptions used for reactor operations, of 2 TPBARs per core (maximum of 3,400 TPBARs per core). Since the possibility exists that the 2 assumed failed TPBARs could be transported in the same cask shipment following consolidation at the reactor, the EIS transportation risk analyses assumed that there could be a maximum of 2 prefailed (failed prior to transportation) TPBARs in a truck cask (at least 289 TPBARs per shipment) or a given rail cask (at least 578 TPBARs per shipment).

Following design-basis accident impacts, spent fuel rods with precracking due to pellet-clad interactions at the pellet boundaries experience very few failures (SNL 1992). Therefore, the analysis assumes that the regulatory impact ($S_1 = 0.2$ percent) will not cause any TPBAR cladding failures. Moreover, the design conservatism in the impact limiters for spent fuel casks results in only relatively small increases in acceleration loads to the contents for extra-regulatory impacts up to a point where the strain in the wall is equal to 2 percent. Therefore, it is assumed that there are no failures of the TPBAR cladding for impact loads resulting in strains below S_2 (2 percent). To achieve strains higher than 2 percent, the impact limiter must be completely locked up (can no longer absorb energy) and the acceleration levels increase significantly. At this point there is a possibility that some of the TPBARs could experience cladding failure due to the mechanical loads placed upon them. Considering the high ductility of the TPBAR cladding, it was assumed that the only TPBARs that can fail during impact loads are those with pre-existing part-wall cracks (SNL 1999). These analyses conservatively assumed that this is equal to 1 percent of the TPBARs, based on the frequency of spent fuel rods with pre-existing part-wall cracks (SNL 1992). The failed TPBARs would release all of their tritium inventories (PNNL 1999).

As noted earlier, the temperatures that define the regions for the conditional probabilities in the Modal Study truck and rail cask accident matrices are the temperatures at the mid-wall of the lead shield that result from thermal loads during the fire accident. The temperature of the TPBAR cladding is conservatively assumed to be equal to lead shield mid-wall temperature. For temperatures below T_3 (343°C), the EIS analyses assume that 0.12 millicurie per TPBAR per hour of tritium in the form of molecular tritium gas (T_2 and HT) are released from all intact TPBARs into the cask cavity (PNNL 1999). For the purposes of determining the quantity of molecular tritium gas that is released from intact TPBARs into the cask cavity, the EIS analyses conservatively assume that the TPBARs are in the transport cask for a period of two weeks. For the purpose of analysis, each TPBAR is designed to contain an average of 1 gram of tritium, or approximately 9,640 Curies (PNNL 1997). For temperatures between T_3 and T_4 (343° and 565°C), the EIS analyses assume that

0.015 grams of tritium/TPBAR in the form of molecular tritium gas are released from all intact TPBARs into the cask cavity (PNNL 1999).

For temperatures below T_4 , the EIS analyses assume that 0.015 grams of tritium/TPBAR in the form of tritiated water (T_2O and HTO) are instantaneously released into the cask cavity from all TPBARs that have failed due to impact and thermal loads (PNNL 1999). The potential for TPBAR rupture was assessed at T_4 , and it was determined that TPBARs are unlikely to rupture at temperatures less than T_4 . However, TPBARs may rupture at temperatures higher than T_4 . Therefore, the analyses conservatively assume that all TPBARs fail during a transportation cask fire accident when TPBAR temperatures are above T_4 . For TPBARs with temperatures above T_4 , the analyses assume that 100 percent of the tritium inventory of the TPBARs is instantaneously released in the form of tritiated water into the cask cavity (PNNL 1999).

Finally, the EIS analyses assume that 100 percent of the tritium inventory of prefabricated (failed prior to transportation) TPBARs will be released into the cask cavity in the form of tritiated water (PNNL 1999) and that tritiated water does not permeate through the elastomeric seals comprising the cask containment boundary for temperatures less than T_1 (260°C) or through the metallic seals comprising the cask containment boundary for temperatures less than T_4 .

E.5.7.3 Accident Matrix Category Descriptions

The six accident categories specified in DOE/EA-1210 (DOE 1997) and shown in Figure E-6 were based on the performance of spent nuclear fuel. The analysis described in Section E.5.7.2 has been used to refine the category descriptions to better fit the characteristic behavior of TPBARs. Retaining the basic structure of the Modal Study matrices allows the use of the conditional probabilities given in the Modal Study for accident matrix regions.

The 20 regions described by the 4×5 conditional probability matrix were combined to give seven accident severity categories for the truck and rail casks used to transport the irradiated TPBARs from the production reactor to the Tritium Extraction Facility. The regions of the conditional probability matrix that are encompassed by a specific accident category will differ between a cask using elastomeric seals and one using metallic seals, due to the varying response of each cask to the impact and thermal loads.

E.5.7.3.1 Elastomeric Seals

Figure E-9 gives the accident matrix for both truck and rail casks using an elastomeric seal. The regions that were combined to generate the seven accident categories are also shown in Figure E-9.

E.5.7.3.2 Metallic Seals

Figure E-10 gives the accident matrix for both truck and rail casks using a metallic seal. The regions that were combined to generate each of the seven accident categories are also shown in Figure E-10.

Strain	S_3 30%	R(4,1)	R(4,2) Category 5	R(4,3)	R(4,4) Category 6	R(4,5)
		R(3,1)	R(3,2)	R(3,3)	R(3,4)	R(3,5) Category 7
	S_2 2%	R(2,1) Category 2	R(2,2)	R(2,3)	R(2,4)	R(2,5)
	S_1 0.2%	R(1,1) Category 1	R(1,2)	R(1,3)	R(1,4)	R(1,5)
		T_1 260°C	T_2 316°C	T_3 343°C	T_4 565°C	
		Temperature				

Figure E–9 Accident Matrix for Truck and Rail Casks Using Elastomeric Seals

Strain	S_3 30%	R(4,1)	R(4,2) Category 5	R(4,3)	R(4,4) Category 6	R(4,5)
		R(3,1)	R(3,2)	R(3,3)	R(3,4)	R(3,5) Category 7
	S_2 2%	R(2,1)	R(2,2)	R(2,3)	R(2,4)	R(2,5)
	S_1 0.2%	R(1,1) Category 1	R(1,2)	R(1,3) Category 2	R(1,4)	R(1,5)
		T_1 260°C	T_2 316°C	T_3 343°C	T_4 565°C	
		Temperature				

Figure E–10 Accident Matrix for Truck and Rail Casks Using Metallic Seals

E.5.7.3.3 Accident Category Release Fractions for Tritium, Nontarget-Bearing Components, and Crud

Release fractions for tritium, both as molecular tritium gas (T_2 or HT) and as tritiated water (T_2O or HTO); nontarget-bearing components; and crud for truck casks transported by road, truck casks transported by rail, and rail casks transported by rail, with no prefailed TPBARs, are given in **Table E–3** for each of the seven accident categories. For both regulatory and extra-regulatory transport conditions, 100 percent of the crud is assumed to spall. The average crud concentration in a cask cavity can be expressed as the concentration immediately after spallation and initial mixing, multiplied by a release reduction factor that incorporates all geometrical information on the cask volume, settling, and collection areas, and the aerosols time-varying size

distribution (SNL 1993a). A bounding maximum release fraction for crud based on 100-percent spallation and typical release reduction factors is 2×10^{-3} (SNL 1991b). Release fractions for nontarget-bearing components are equivalent to those used in DOE/EA-1210 (DOE 1997) for the Lead Test Assembly, with adjustments made for the accident categories that are defined by different regions of the matrix. The crud and nontarget-bearing components release fractions are independent of whether the cask uses an elastomeric seal or a metallic seal.

Table E-3 Release Fractions for Truck and Rail Casks with No Prefailed TPBARs

Category	1	2	3	4	5	6	7
T ₂ / HT	0	0	4.18×10^{-6}	4.18×10^{-6}	4.18×10^{-6}	4.18×10^{-6}	4.18×10^{-6}
T ₂ O / HTO	0	0	0	1.5×10^{-2}	1.0×10^{-2}	2.5×10^{-2}	1.0
NTBC	0	0	3.1×10^{-10}	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-7}
Crud	0	0	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}

T₂ / HT = molecular tritium gas.

T₂O / HTO = tritiated water.

NTBC = Nontarget-bearing components.

Release fractions for tritium, non-target-bearing components, and crud for truck casks transported by road and truck casks transported by rail with two prefailed TPBARs out of 289 TPBARs are given in **Table E-4** for each of the seven accident categories. The release fractions are independent of whether the cask uses an elastomeric seal or a metallic seal.

Table E-4 Release Fractions for Truck Casks with Two Prefailed TPBARs

Category	1	2	3	4	5	6	7
T ₂ / HT	0	0	4.15×10^{-6}	4.15×10^{-6}	4.15×10^{-6}	4.15×10^{-6}	4.15×10^{-6}
T ₂ O / HTO	0	0	8.29×10^{-3}	2.32×10^{-2}	1.83×10^{-2}	3.32×10^{-2}	1.0
NTBC	0	0	3.1×10^{-10}	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-7}
Crud	0	0	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}

T₂ / HT = molecular tritium gas.

T₂O / HTO = tritiated water.

NTBC = Nontarget-bearing components.

Release fractions for tritium, nontarget-bearing components, and crud for rail casks transported by rail with two prefailed TPBARs out of 578 TPBARs in two consolidated containers in the rail cask are given in **Table E-5** for each of the seven accident categories. The release fractions are independent of whether the cask uses an elastomeric seal or a metallic seal.

Table E-5 Release Fractions for Rail Casks with Two Prefailed TPBARs

Category	1	2	3	4	5	6	7
T ₂ / HT	0	0	4.17×10^{-6}	4.17×10^{-6}	4.17×10^{-6}	4.17×10^{-6}	4.17×10^{-6}
T ₂ O / HTO	0	0	4.15×10^{-3}	1.91×10^{-2}	1.42×10^{-2}	2.91×10^{-2}	1.0
NTBC	0	0	3.1×10^{-10}	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-7}
Crud	0	0	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}

T₂ / HT = molecular tritium gas.

T₂O / HTO = tritiated water.

NTBC = Nontarget-bearing components.

E.5.7.3.4 Accident Category Severity Fractions

The conditional probabilities given in Figure E-6, Figure E-7, and Figure E-8 were combined using the accident categories depicted in Figures E-9 and E-10 to develop the accident category severity fractions given in **Table E-6**. The severity fractions are independent of whether there are any prefailed TPBARs, since the conditional probability accident matrix category descriptions are the same whether there are no prefailed TPBARs or there are two prefailed TPBARs in the transport cask.

Table E-6 Accident Category Severity Fractions

	<i>Category</i>						
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>
Truck cask transported by road using elastomeric seals	0.99432	3.819×10^{-3}	4.102×10^{-5}	1.541×10^{-5}	1.799×10^{-3}	1.076×10^{-7}	9.641×10^{-6}
Truck cask transported by rail using elastomeric seals	0.99380	2.720×10^{-3}	1.653×10^{-3}	9.812×10^{-4}	5.546×10^{-4}	6.565×10^{-8}	4.917×10^{-4}
Rail cask transported by rail using elastomeric seals	0.99396	2.720×10^{-3}	2.023×10^{-3}	6.143×10^{-4}	5.547×10^{-4}	5.162×10^{-8}	1.250×10^{-4}
Truck cask transported by road using metallic seals	0.99432	5.574×10^{-5}	3.828×10^{-3}	1.542×10^{-7}	1.799×10^{-3}	1.076×10^{-7}	9.641×10^{-6}
Truck cask transported by rail using metallic seals	0.99380	2.433×10^{-3}	2.721×10^{-3}	3.219×10^{-7}	5.546×10^{-4}	6.565×10^{-8}	4.917×10^{-4}
Rail cask transported by rail using metallic seals	0.99396	2.637×10^{-3}	2.721×10^{-3}	2.531×10^{-7}	5.547×10^{-4}	5.162×10^{-8}	1.250×10^{-4}

E.5.8 Nonradiological Risk (Vehicle-Related)

Vehicle-related health risks resulting from incident-free transport may be associated with the generation of air pollutants by transport vehicles during shipment and are independent of the radioactive nature of the shipment. The health endpoint assessed under incident-free transport conditions is the excess latent mortality due to inhalation of vehicle exhaust emissions. Risk factors for pollutant inhalation in terms of latent mortality have been generated (SNL 1982). These risks are 1×10^{-7} mortality per kilometer (1.6×10^{-7} per mile) and 1.3×10^{-7} mortality per kilometer (2.1×10^{-7} per mile) of truck and rail travel in urban areas, respectively. The risk factors are based on regression analyses of the effects of sulfur dioxide and particulate releases from diesel exhaust on mortality rates. Excess latent mortalities are assumed to be equivalent to latent cancer fatalities. Vehicle-related risks from incident-free transportation are calculated for each case by multiplying the total distance traveled in urban areas by the appropriate risk factor. Similar data are not available for rural and suburban areas.

Risks are summed over the entire route and over all shipments for each case. This method has been used in several EISs to calculate risks from incident-free transport. Lack of information for rural and suburban areas is an obvious data gap, although the risk factor would presumably be lower than for urban areas because of lower total emissions from all sources and lower population densities in rural and suburban areas.

E.6 RISK ANALYSIS RESULTS

Per-shipment risk factors have been calculated for the collective populations of exposed persons and for the crew for all anticipated routes and shipment configurations. The radiological risks are presented in doses per shipment for each unique route, material, and container combination. The radiological dose per shipment factors for incident-free transportation are presented in **Table E-7**. Doses are calculated for the crew, off-link public (i.e., people living along the route), on-link public (i.e., pedestrians and drivers along the route), and the public at rest and fueling stops (i.e., stopped cars, buses and trucks, workers, and other bystanders).

Accident impacts were calculated under the conservative assumption that all tritium gas released is quickly oxidized to form tritiated water.

The radiological dose risk factors for accident transportation conditions are also presented in Table E-7. The accident risk factors are called “dose risk,” because the values incorporate the spectrum of accident severity probabilities and associated consequences. They are presented for normal transportation (i.e., no failed TPBARs) and the abnormal event of two failed TPBARs in a shipment. The risks are only slightly higher if the failed TPBARs were to be shipped in a single cask.

The nonradiological risk factors are presented in fatalities per shipment in **Table E-8**. Separate risk factors are provided for fatalities resulting from exhaust emissions (caused by hydrocarbon emissions known to be carcinogens) and transportation accidents (fatalities resulting from impact).

The performance of both elastomeric and metallic cask seals was evaluated. Elastomeric seals perform better in accidents that involve impact because they are more flexible. Metallic seals perform better in accidents that involve fire because they are less susceptible to heat damage. Overall, metallic seals exhibit a slightly higher risk and, therefore, are used to evaluate EIS alternatives.

Table E-9 shows the risks of transporting each of the hazardous materials. The risks are calculated by multiplying the previously given per-shipment factors by the number of shipments over 40 years’ duration of the program and, in the case of the radiological doses, by the health risk conversion factors. The accident risk from TPBAR shipments includes the irradiated metal and the crud deposited onto the TPBARs. Over 90 percent of the accident risk comes from the tritium. Based on the results of the transportation risk analysis, it is unlikely that shipping TPBARs and waste will result in a fatality. The risk estimates include the highest conceivable impacts of shipping unirradiated TPBARs and assemblies.

The risks to various exposed individuals under incident-free transportation conditions have been estimated for hypothetical exposure scenarios. The estimated doses to inspectors and the public are presented in **Table E-10** on a per-event basis (person-rem per event). Note that the potential exists for larger individual exposures if multiple exposure events occur. For example, the dose to a person stuck in traffic next to a shipment for 30 minutes is calculated to be 11 millirem. If the exposure duration were longer, the dose would rise proportionally. In addition, a person working at a truck service station could receive a significant dose if trucks were to use the same stops repeatedly. The dose to a person fueling a truck could be as much as 1 millirem. Administrative controls could be instituted to control the location and duration of truck stops if multiple exposures were to happen routinely.

The cumulative dose to a resident was calculated assuming all shipments passed his or her home. The cumulative doses assume that the resident is present for every shipment and is unshielded at a distance of 30 meters (about 100 feet) from the route. Therefore, the cumulative dose is only a function of the number of shipments passing a particular point and is independent of the actual route being considered. The maximum dose to this resident, if all the material were to be shipped via this route, would be less than 0.1 millirem.

The estimated dose to transportation crew members is presented for a commercial crew. No credit is taken for the shielding associated with the tractor or trailer.

Table E-7 Radiological Risk Factors for Single Shipments

From	To	Material & Package	Incident-Free Dose (Person-rem)					Accident Dose (Person-rem)
			Crew	Public				
				Off-link	On-link	Stops	Total	
No Failed TPBARs								
Truck Routes								
Watts Bar Nuclear Plant	Savannah River Site	Irradiated TPBARs	1.4×10^{-2}	2.4×10^{-3}	1.3×10^{-2}	6.8×10^{-2}	8.4×10^{-2}	3.2×10^{-5}
Sequoyah Nuclear Plant	Savannah River Site	Irradiated TPBARs	1.3×10^{-2}	2.9×10^{-3}	1.7×10^{-2}	5.9×10^{-2}	7.9×10^{-2}	3.7×10^{-5}
Bellefonte Nuclear Plant	Savannah River Site	Irradiated TPBARs	1.4×10^{-2}	2.3×10^{-3}	1.4×10^{-2}	6.6×10^{-2}	8.2×10^{-2}	4.0×10^{-5}
Rail Routes								
Watts Bar Nuclear Plant	Savannah River Site	Irradiated TPBARs - Rail Cask	1.2×10^{-3}	7.5×10^{-4}	1.6×10^{-4}	4.8×10^{-3}	5.7×10^{-3}	2.0×10^{-5}
Watts Bar Nuclear Plant	Savannah River Site	Irradiated TPBARs - 2 Truck Casks	1.2×10^{-3}	7.5×10^{-4}	1.6×10^{-4}	4.9×10^{-3}	5.8×10^{-3}	7.0×10^{-5}
Sequoyah Nuclear Plant	Savannah River Site	Irradiated TPBARs - Rail Cask	1.1×10^{-3}	6.9×10^{-4}	1.5×10^{-4}	4.7×10^{-3}	5.6×10^{-3}	1.8×10^{-5}
Sequoyah Nuclear Plant	Savannah River Site	Irradiated TPBARs - 2 Truck Casks	1.1×10^{-3}	6.9×10^{-4}	1.5×10^{-4}	4.8×10^{-3}	5.6×10^{-3}	6.5×10^{-5}
Bellefonte Nuclear Plant	Savannah River Site	Irradiated TPBARs - Rail Cask	1.2×10^{-3}	7.5×10^{-4}	1.6×10^{-4}	4.8×10^{-3}	5.7×10^{-3}	2.0×10^{-5}
Bellefonte Nuclear Plant	Savannah River Site	Irradiated TPBARs - 2 Truck Casks	1.2×10^{-3}	7.6×10^{-4}	1.6×10^{-4}	4.9×10^{-3}	5.8×10^{-3}	7.1×10^{-5}
2 Failed TPBARs								
Truck Routes								
Watts Bar Nuclear Plant	Savannah River Site	Irradiated TPBARs	1.4×10^{-2}	2.4×10^{-3}	1.3×10^{-2}	6.8×10^{-2}	8.4×10^{-2}	4.0×10^{-5}
Sequoyah Nuclear Plant	Savannah River Site	Irradiated TPBARs	1.3×10^{-2}	2.9×10^{-3}	1.7×10^{-2}	5.9×10^{-2}	7.9×10^{-2}	6.1×10^{-5}
Bellefonte Nuclear Plant	Savannah River Site	Irradiated TPBARs	1.4×10^{-2}	2.3×10^{-3}	1.4×10^{-2}	6.6×10^{-2}	8.2×10^{-2}	5.4×10^{-5}

From	To	Material & Package	Incident-Free Dose (Person-rem)					Accident Dose (Person-rem)
			Crew	Public				
				Off-link	On-link	Stops	Total	
All Metallic Seals								
Rail Routes								
Watts Bar Nuclear Plant	Savannah River Site	Irradiated TPBARs - Rail Cask	1.2×10^{-3}	7.5×10^{-4}	1.6×10^{-4}	4.8×10^{-3}	5.7×10^{-3}	2.0×10^{-5}
Watts Bar Nuclear Plant	Savannah River Site	Irradiated TPBARs - 2 Truck Casks	1.2×10^{-3}	7.5×10^{-4}	1.6×10^{-4}	4.9×10^{-3}	5.8×10^{-3}	7.1×10^{-5}
Sequoyah Nuclear Plant	Savannah River Site	Irradiated TPBARs - Rail Cask	1.1×10^{-3}	6.9×10^{-4}	1.5×10^{-4}	4.7×10^{-3}	5.6×10^{-3}	1.8×10^{-5}
Sequoyah Nuclear Plant	Savannah River Site	Irradiated TPBARs - 2 Truck Casks	1.1×10^{-3}	6.9×10^{-4}	1.5×10^{-4}	4.8×10^{-3}	5.6×10^{-3}	6.6×10^{-5}
Bellefonte Nuclear Plant	Savannah River Site	Irradiated TPBARs - Rail Casks	1.2×10^{-3}	7.5×10^{-4}	1.6×10^{-4}	4.8×10^{-3}	5.7×10^{-3}	2.0×10^{-5}
Bellefonte Nuclear Plant	Savannah River Site	Irradiated TPBARs - 2 Truck Casks	1.2×10^{-3}	7.6×10^{-4}	1.6×10^{-4}	4.9×10^{-3}	5.8×10^{-3}	7.2×10^{-5}
Waste Transport								
Truck Routes								
Watts Bar Nuclear Plant	Savannah River Site	Low-Level Radioactive Waste	1.9×10^{-2}	1.7×10^{-3}	6.2×10^{-3}	6.8×10^{-2}	7.6×10^{-2}	$<1.0 \times 10^{-8}$
Sequoyah Nuclear Plant	Savannah River Site	Low-Level Radioactive Waste	1.7×10^{-2}	1.7×10^{-3}	5.9×10^{-3}	5.9×10^{-2}	6.7×10^{-2}	$<1.0 \times 10^{-8}$
Bellefonte Nuclear Plant	Savannah River Site	Low-Level Radioactive Waste	1.2×10^{-2}	1.0×10^{-3}	3.9×10^{-3}	4.3×10^{-2}	4.7×10^{-2}	$<1.0 \times 10^{-8}$
Watts Bar Nuclear Plant	Barnwell	Low-Level Radioactive Waste	2.0×10^{-2}	1.7×10^{-3}	6.6×10^{-3}	7.5×10^{-2}	8.3×10^{-2}	$<1.0 \times 10^{-8}$
Sequoyah Nuclear Plant	Barnwell	Low-Level Radioactive Waste	1.9×10^{-2}	1.8×10^{-3}	6.3×10^{-3}	6.6×10^{-2}	7.4×10^{-2}	$<1.0 \times 10^{-8}$
Bellefonte Nuclear Plant	Barnwell	Low-Level Radioactive Waste	2.0×10^{-2}	1.7×10^{-3}	6.5×10^{-3}	7.3×10^{-2}	8.1×10^{-2}	$<1.0 \times 10^{-8}$

The accident consequence assessment is intended to provide an estimate of the maximum potential impacts posed by the most severe potential transportation accidents involving a shipment. The maximum foreseeable (frequency greater than 1×10^{-7} per year) offsite transportation accident involves a shipment of irradiated TPBARs under neutral (average) weather conditions. The accident has a probability of occurring about once every 10 million years and could result in a 5.9 rem to a person 30 meters (about 100 feet) from the vehicle. The probability of an accident occurring is smaller with failed TPBARs or under stable atmospheric conditions. This accident would fall into Category 5 of the previously described accident matrix shown in Figure E-9. In this hypothetical accident, the impact would cause the cask to fail, and the deformation of the cask would be assumed to fail 1 percent of the TPBARs. In the event of a fire, it would not be hot enough or would be too short in duration to damage the TPBARs. To incur this level of damage, the cask would have to collide with an immovable object at a speed much greater than 88.5 kilometers per hour (55 miles per hour). The probability of an accident with a more energetic collision or fire and higher consequences is lower.

Table E-8 Nonradiological Risk Factors per Shipment

<i>Nonradiological Risk Estimates (Fatalities/Shipment)</i>			
<i>From</i>	<i>To</i>	<i>Exhaust Emission</i>	<i>Accident</i>
Truck Routes			
Watts Bar Nuclear Plant	Savannah River Site	1.95×10^{-6}	1.13×10^{-5}
Sequoyah Nuclear Plant	Savannah River Site	2.20×10^{-6}	9.87×10^{-6}
Bellefonte Nuclear Plant	Savannah River Site	2.13×10^{-6}	1.10×10^{-5}
Wilmington, NC	Columbia, SC	2.05×10^{-7}	9.97×10^{-6}
Wilmington, NC	Lynchburg, VA	4.04×10^{-7}	1.11×10^{-5}
Wilmington, NC	Richland, WA	5.75×10^{-6}	9.26×10^{-5}
Wilmington, NC	Hematite, MO	1.34×10^{-6}	3.26×10^{-5}
Columbia, SC	Lynchburg, VA	7.74×10^{-7}	1.16×10^{-5}
Columbia, SC	Richland, WA	5.34×10^{-6}	8.60×10^{-5}
Hematite, MO	Columbia, SC	1.20×10^{-6}	2.59×10^{-5}
Hematite, MO	Watts Bar Nuclear Plant	7.34×10^{-7}	1.77×10^{-5}
Lynchburg, VA	Watts Bar Nuclear Plant	4.92×10^{-7}	1.20×10^{-5}
Columbia, SC	Watts Bar Nuclear Plant	4.97×10^{-7}	1.08×10^{-5}
Richland, WA	Watts Bar Nuclear Plant	4.84×10^{-6}	7.77×10^{-5}
Lynchburg, VA	Sequoyah Nuclear Plant	8.02×10^{-7}	1.43×10^{-5}
Columbia, SC	Sequoyah Nuclear Plant	2.03×10^{-6}	1.18×10^{-5}
Hematite, MO	Sequoyah Nuclear Plant	8.37×10^{-7}	1.62×10^{-5}
Richland, WA	Sequoyah Nuclear Plant	5.14×10^{-6}	7.63×10^{-5}
Lynchburg, VA	Bellefonte Nuclear Plant	7.11×10^{-7}	1.54×10^{-5}
Columbia, SC	Bellefonte Nuclear Plant	1.97×10^{-6}	1.29×10^{-5}
Hematite, MO	Bellefonte Nuclear Plant	7.30×10^{-7}	1.57×10^{-5}
Richland, WA	Bellefonte Nuclear Plant	5.10×10^{-6}	7.57×10^{-5}
Watts Bar Nuclear Plant	Barnwell, SC	1.77×10^{-6}	1.24×10^{-5}
Sequoyah Nuclear Plant	Barnwell, SC	2.06×10^{-6}	1.10×10^{-5}
Bellefonte Nuclear Plant	Barnwell, SC	1.98×10^{-6}	1.21×10^{-5}
Rail Routes			
Watts Bar Nuclear Plant	Savannah River Site	1.13×10^{-6}	1.57×10^{-5}
Sequoyah Nuclear Plant	Savannah River Site	1.11×10^{-6}	1.44×10^{-5}
Bellefonte Nuclear Plant	Savannah River Site	1.05×10^{-6}	1.59×10^{-5}

Table E–9 Risks of Transporting the Hazardous Materials

Reactor Site (No. of TPBARs)	TPBAR Transportation Mode	Incident-Free			Accident	
		Radiological		Nonradiological		Radiological
		Crew	Public	Emission	Traffic	
Watts Bar (3,400 TPBARs/cycle)	Truck Cask via Truck	0.0033	0.021	0.0032	0.031	5.1×10^{-6}
	Truck Cask via Rail	0.0016	0.008	0.0023	0.029	5.7×10^{-6}
	Rail Cask via Rail	0.0016	0.008	0.0023	0.029	1.6×10^{-6}
Sequoyah (3,400 TPBARs/cycle)	Truck Cask via Truck	0.0030	0.019	0.0035	0.029	6.1×10^{-6}
	Truck Cask via Rail	0.0014	0.007	0.0024	0.028	5.2×10^{-6}
	Rail Cask via Rail	0.0014	0.007	0.0024	0.028	1.5×10^{-6}
Bellefonte (3,400 TPBARs/cycle)	Truck Cask via Truck	0.0026	0.018	0.0034	0.030	6.4×10^{-6}
	Truck Cask via Rail	0.0010	0.005	0.0024	0.028	5.8×10^{-6}
	Rail Cask via Rail	0.0010	0.005	0.0024	0.028	1.6×10^{-6}
Watts Bar (1,000 TPBARs/cycle)	Truck Cask via Truck	0.0010	0.007	0.0010	0.009	1.7×10^{-6}
	Truck Cask via Rail	0.0005	0.002	0.0007	0.009	1.9×10^{-6}
	Rail Cask via Rail	0.0005	0.002	0.0007	0.009	5.3×10^{-7}
Sequoyah (1,000 TPBARs/cycle)	Truck Cask via Truck	0.0009	0.006	0.0011	0.009	2.0×10^{-6}
	Truck Cask via Rail	0.0004	0.002	0.0007	0.008	1.7×10^{-6}
	Rail Cask via Rail	0.0004	0.002	0.0007	0.008	4.9×10^{-7}
Bellefonte (1,000 TPBARs/cycle)	Truck Cask via Truck	0.0008	0.006	0.0010	0.009	2.1×10^{-6}
	Truck Cask via Rail	0.0003	0.001	0.0007	0.009	1.9×10^{-6}
	Rail Cask via Rail	0.0003	0.001	0.0007	0.009	5.4×10^{-7}

Maximum impacts are assumed for fabrication, assembly, and waste transportation, and are included in these totals.

All risks are expressed as number of latent cancer fatalities, except for the Accident-Traffic column, which lists number of accident fatalities.

Table E-10 Estimated Dose to Exposed Individuals During Incident-Free Transportation Conditions

<i>Receptor</i>		<i>Dose to Maximally Exposed Individual^a</i>
Workers	Crew member (truck driver)	0.1 rem per year ^b
	Inspector	0.0029 rem per event
Public	Resident	4.0×10^{-7} rem per event
	Person in traffic congestion	0.011 rem per event
	Person at service station	0.001 rem per event

rem = roentgen equivalent man.

^a Doses are calculated assuming that the shipment external dose rate is equal to the maximum expected dose of 10 millirem per hour at 2 meters (6.6 feet) from the package.

^b This is a dose limit for a nonradiation worker (10 CFR 20). The truck driver dose could exceed this limit in the absence of administrative controls.

E.7 CONCLUSIONS AND LONG-TERM IMPACTS OF TRANSPORTATION

E.7.1 Conclusions

It is unlikely that the transportation of radioactive materials will cause an additional fatality.

E.7.2 Long-Term Impacts of Transportation

The *Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* (DOE 1995) analyzed the cumulative impacts of all transportation of radioactive materials, including impacts from reasonably foreseeable actions that include transportation of radioactive material for a specific purpose and general radioactive materials transportation that is not related to a particular action. The total worker and general population collective doses are summarized in **Table E-11**. The table shows that the impacts of this program are quite small compared with overall transportation impacts. Total collective worker doses from all types of shipments (historical, the alternatives, reasonably foreseeable actions, and general transportation) were estimated to be 320,000 person-rem (130 latent cancer fatalities) for the period 1943 through 2035 (93 years). Total general population collective doses were also estimated to be 320,000 person-rem (160 latent cancer fatalities). The majority of the collective dose for workers and the general population was due to the general transportation of radioactive material. Examples of these activities are shipments of radiopharmaceuticals to nuclear medicine laboratories and shipments of commercial low-level radioactive waste to commercial disposal facilities. The total number of latent cancer fatalities estimated to result from radioactive materials transportation over the period between 1943 and 2035 was 290. Over this same period (93 years), approximately 28 million people would die from cancer, based on 300,000 cancer fatalities per year (10 CFR 71). It should be noted that the estimated number of transportation-related latent cancer fatalities would be indistinguishable from other latent cancer fatalities, and the transportation-related latent cancer fatalities are 0.0010 percent of the total number of latent cancer fatalities.

Table E-11 Cumulative Transportation-Related Radiological Collective Doses and Latent Cancer Fatalities (1943 to 2035)

<i>Category</i>	<i>Collective Worker Dose (person-rem)</i>	<i>Collective General Population Dose (person-rem)</i>
CLWR Impacts		
Shipment of TPBARs and LLW	< 100	< 100
Latent cancer fatalities from TPBARs and LLW	<1	<1
Other Nuclear Material Shipments		
Reasonably foreseeable actions ^a		
Truck	11,000	50,000
Rail	820	1,700
General transportation (1943–2035)	310,000	270,000
Total collective dose	320,000	320,000
Total Latent Cancer Fatalities	130	160

^a LLW = Low-Level Radioactive Waste.

Source: DOE 1995.

E.8 UNCERTAINTY AND CONSERVATISM IN ESTIMATED IMPACTS

The sequence of analyses performed to generate the estimates of radiological risk for transportation includes: (1) determination of the inventory and characteristics, (2) estimation of shipment requirements, (3) determination of route characteristics, (4) calculation of radiation doses to exposed individuals (including estimation of environmental transport and uptake of radionuclides), and (5) estimation of health effects. Uncertainties are associated with each of these steps. Uncertainties exist in the way that the physical systems being analyzed are represented by the computational models; in the data required to exercise the models (due to measurement errors, sampling errors, natural variability, or unknowns simply caused by the future nature of the actions being analyzed); and in the calculations themselves (e.g., approximate algorithms used by the computers).

In principle, one can estimate the uncertainty associated with each input or computational source and predict the resultant uncertainty in each set of calculations. Thus, one can propagate the uncertainties from one set of calculations to the next and estimate the uncertainty in the final, or absolute, result; however, conducting such a full-scale quantitative uncertainty analysis is often impractical and sometimes impossible, especially for actions to be initiated at an unspecified time in the future. Instead, the risk analysis is designed to ensure, through uniform and judicious selection of scenarios, models, and input parameters, that relative comparisons of risk among the various alternatives are meaningful. In the transportation risk assessment, this design is accomplished by uniformly applying common input parameters and assumptions to each alternative. Therefore, although considerable uncertainty is inherent in the absolute magnitude of the transportation risk for each alternative, much less uncertainty is associated with the relative differences among the alternatives in a given measure of risk.

In the following sections, areas of uncertainty are discussed for the assessment steps enumerated above. Special emphasis is placed on identifying whether the uncertainties affect relative or absolute measures of risk. The degree of reality conservatism of the assumption is addressed. Where practical, the parameters that most significantly affect the risk assessment results are identified.

E.8.1 Uncertainties in TPBAR and Radioactive Waste Inventory and Characterization

The inventories and the physical and radiological characteristics are important input parameters of the transportation risk assessment. The potential amount of transportation for any alternative is determined primarily by the projected dimensions of package contents and, in the case of irradiated TPBARs, the strength of the radiation field and assumptions concerning shipment capacities. The physical and radiological characteristics are important in determining the amount of material released during accidents and the subsequent doses to exposed individuals through multiple environmental exposure pathways.

Uncertainties in the inventory and characterization will be reflected to some degree in the transportation risk results. If the inventory is overestimated (or underestimated), the resulting transportation risk estimates also will be overestimated (or underestimated) by roughly the same factor. However, the same inventory estimates are used to analyze the transportation impacts of each of the EIS alternatives. Therefore, for comparative purposes, the observed differences in transportation risks among the proposed reactor sites as given in Table E-9 are believed to represent unbiased, reasonably accurate estimates from current information in terms of relative risk comparisons.

If DOE should enter into the final design and implementation phase of the project, the amount of tritium in the TPBARs could change. The incident-free risk estimate would not change unless the number of shipments changes, because the maximum regulatory limit dose rate was used. However, since over 90 percent of the accident impact comes from the tritium in the TPBARs, the accident impact would increase or decrease in proportion to the amount of tritium in the TPBARs.

E.8.2 Uncertainties in Containers, Shipment Capacities, and Number of Shipments

The amount of transportation required for each alternative is based in part on assumptions concerning the packaging characteristics and shipment capacities for commercial trucks and safe secure transports. Representative shipment capacities have been defined for assessment purposes based on probable future shipment capacities. In reality, the actual shipment capacities may differ from the predicted capacities such that the projected number of shipments and, consequently, the total transportation risk would change. However, although the predicted transportation risks would increase or decrease accordingly, the relative differences in risks among alternatives would remain about the same. The maximum amount of material allowed in Type B containers is set by conservative safety analyses.

E.8.3 Uncertainties in Route Determination

Representative routes have been determined between all origin and destination sites considered in the EIS. The routes have been determined consistent with current guidelines, regulations, and practices, but may not be the actual routes that would be used in the future. In reality, the actual routes could differ from the representative ones in terms of distances and total population along the routes. Moreover, since TPBARs and waste could be transported over an extended period of time starting at some time in the future, the highway infrastructures and the demographics along routes could change. These effects have not been accounted for in the transportation assessment; however, it is not anticipated that these changes would significantly affect relative comparisons of risk among the alternatives considered in the EIS. Specific routes cannot be identified in advance because the routes are classified to protect national security interests.

E.8.4 Uncertainties in the Calculation of Radiation Doses

The models used to calculate radiation doses from transportation activities introduce a further uncertainty in the risk assessment process. It is generally difficult to estimate the accuracy or absolute uncertainty of the risk assessment results. The accuracy of the calculated results is closely related to the limitations of the

computational models and to the uncertainties in each of the input parameters that the model requires. The single greatest limitation facing users of RADTRAN, or any computer code of this type, is the scarcity of data for certain input parameters.

Uncertainties associated with the computational models are minimized by using state-of-the-art computer codes that have undergone extensive review. Because there are numerous uncertainties that are recognized but difficult to quantify, assumptions are made at each step of the risk assessment process that are intended to produce conservative results (i.e., overestimate the calculated dose and radiological risk). Because parameters and assumptions are applied to all alternatives, this model bias is not expected to affect the meaningfulness of relative comparisons of risk; however, the results may not represent risks in an absolute sense.

To understand the most important uncertainties and conservatism in the transportation risk assessment, the results for all cases were examined to identify the largest contributors to the collective population risk. The results of this examination are discussed briefly in the following paragraph.

For truck shipments, the largest contributors to the collective population dose, in decreasing order of importance, were found to be: (1) incident-free dose to members of the public at stops, (2) incident-free dose to transportation crew members, (3) incident-free dose to members of the public sharing the route (on-link dose), (4) incident-free dose to members of the public residing along the route (off-link dose), and (5) accident dose risk to members of the public. Approximately 80 percent of the estimated public dose was incurred at stops; 15 percent was received by the on-link population and 5 percent by the off-link population. In general, the accident contribution to the total risk was negligible compared with the incident-free risks.

As shown above, incident-free transportation risks are the dominant component of the total transportation risk. The most important parameter in calculating incident-free doses is the shipment external dose rate (incident-free doses are directly proportional to the shipment external dose rate). For this assessment, it was assumed that all shipments would have an external dose rate at the regulatory limit of 10 millirem per hour at 2 meters. In practice, the external dose rates would vary from shipment to shipment, but would not exceed the regulatory limit.

Finally, the single largest contributor to the collective population doses calculated with RADTRAN was found to be the dose to members of the public at truck stops. Currently, RADTRAN uses a simple point-source approximation for truck-stop exposures and assumes that the total stop time for a shipment is proportional to the shipment distance. The parameters used in the stop model were based on a survey of a very limited number of radioactive material shipments that examined a variety of shipment types in different areas of the country. It was assumed that stops occur as a function of distance, with a stop rate of 0.011 hour per kilometer (0.018 hour per mile). It was further assumed that an average of 50 people at each stop are exposed at a distance of 20 meters (66 feet). In RADTRAN, the population dose is directly proportional to the external shipment dose rate and the number of people exposed and inversely proportional to the square of the distance. The stop rate assumed results in an hour of stop time per 100 kilometers (62 miles) of travel.

Based upon the qualitative discussion with shippers, the parameter values used in the assessment appear to be conservative. However, data do not exist to quantitatively assess the degree of control and the location, frequency, and duration of truck stops. However, based on the regulatory requirements for continuous escort of the material (10 CFR 73) and the requirement for two drivers, it is clear that the trucks would be on the move much of the time until arrival at the destination. Therefore, the calculated impacts are extremely conservative. By using these conservative parameters, the calculations in this EIS are consistent with the RADTRAN default values.

Shielding of exposed populations was not considered. For all incident-free exposure scenarios, no credit was taken for shielding of exposed individuals. In reality, shielding would be afforded by trucks and cars sharing

the transport routes, rural topography, and the houses and buildings in which people reside. Incident-free exposure to external radiation could be reduced significantly, depending on the type of shielding present. For residential houses, shielding factors (i.e., the ratio of shielded to unshielded exposure rates) have been estimated to range from 0.02 to 0.7, with a recommended value of 0.33. If shielding were to be considered for the maximally exposed resident living near a transport route, the calculated doses and risks would be reduced by approximately 70 percent. Similar levels of shielding may be provided to individuals exposed in vehicles. However, consideration of shielding does not significantly affect the overall incident-free risks to the general public.

Post-accident mitigative actions are not considered for dispersal accidents. For severe accidents involving the release and dispersal of radioactive materials in the environment, no post-accident mitigative actions, such as interdiction of crops or evacuation of the accident vicinity, have been considered in this risk assessment. In reality, mitigative actions would take place following an accident in accordance with U.S. Environmental Protection Agency radiation protection guides for nuclear incidents (EPA 1991). The effects of mitigative actions on population accident doses are highly dependent upon the severity, location, and timing of the accident. For this risk assessment, ingestion doses are only calculated for accidents occurring in rural areas (the calculated ingestion doses, however, assume all food grown on contaminated ground is consumed and is not limited to the rural population). Examination of the severe accident consequence assessment results has shown that ingestion of contaminated foodstuffs contributes on the order of 50 percent of the total population dose for rural accidents. Interdiction of foodstuffs would act to reduce, but not eliminate, this contribution.

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